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THE LUBRICATION OF BALL AND ROLLER BEARINGS AT HIGH SPEED*

By A. Fogg † and J. S. Webber ‡

Summary

This paper deals with the lubrication aspects governing the performance of rolling bearings operating in the speed range 6000 to 30,000 r.p.m. and under radial, thrust, and combined loading. Most of the work was carried out on standard ball bearings of 2-inch bore.

Three test machines are described. Factors investigated included: effects of variation in oil feed, including reduction of oil feed to zero; a comparison of various methods of supply of lubricant; and the influence of viscosity and boundary properties of the lubricant.

In general, the criteria of bearing performance were temperature rise and friction. Bearing life was not considered, except where it was determined by instability of thermal conditions, since, under thermal equilibrium, bearing life is largely dependent on factors other than lubrication.

It is concluded that, provided the bearing housings are adequately drained, the rate of oil supply and the method of lubricating high-speed rolling bearings are not critical, and that lubricating oil can be used as a very effective coolant with no appreciable increase in friction. Viscosity of lubricants has little direct effect on performance, but there appears to be a case for good boundary lubricating properties, particularly at elevated temperatures and under combined radial and axial loading.

Introduction

The investigation described in this paper was part of a general research into high-speed bearings carried out in the Engineering Division of the National Physical Laboratory during the years 1940–46. The work was begun at the instigation of the Ministry of Aircraft Production (now Ministry of Supply (Air)), as bearing performance constituted an important factor in the early development of the aircraft gas turbine. The unusual loading, speed, and temperature conditions of the ball and roller bearings proposed for experimental gas turbines made imperative an investigation, *inter alia*, into the lubrication of the bearings. Considerations of heat transfer and, at that time, of their instability ruled out greases as lubricants, and the investigation resolved itself into an analysis of the properties and methods of supply of different oils to produce optimum performance of bearings in the range $1\frac{1}{2}$ to 3 inches bore. Information on performance of such bearings at the speeds, loads, and temperatures of gas turbines was virtually non-existent, for, although high-speed bearings had been in use for such purposes as high-speed grinding spindles, the duty imposed on these had never approached that demanded of the gas turbine bearings. Indeed, bearings designated as "high-speed" were flown to the U.K. from the U.S.A. at an early stage of the investigation, and examined on behalf of organizations in the U.S.A.

* MS received 29 September 1952.

† Director, The Motor Industry Research Association. (Formerly Principal Scientific Officer, Engineering Division, National Physical Laboratory.)

‡ Senior Experimental Officer, Lubrication and Wear Division, M.E.R.L., Thorntonhall, Glasgow.

Owing to the urgency of the problem, much of the earlier work was of an *ad hoc* nature, and was concerned with determining performance under operating conditions specified by various organizations engaged in gas turbine development. This accounts for the rather varied and, perhaps, unsystematic data, particularly concerning bearing type and size, given in parts of this paper.

Test Machines

From the lubricating aspect, the research was basically a comparison of the performance of bearings with different lubricants and methods of supply of lubricants. The criteria of bearing performance adopted were, in general, rise of temperature, wear, and friction, and three rigs were built incorporating equipment for measuring these characteristics. A brief description of these machines is given below.

No. 1 *High-speed Machine*

This machine is illustrated in Fig 1. The two nominally identical ball bearings under test are mounted on either side of a collar turned on the

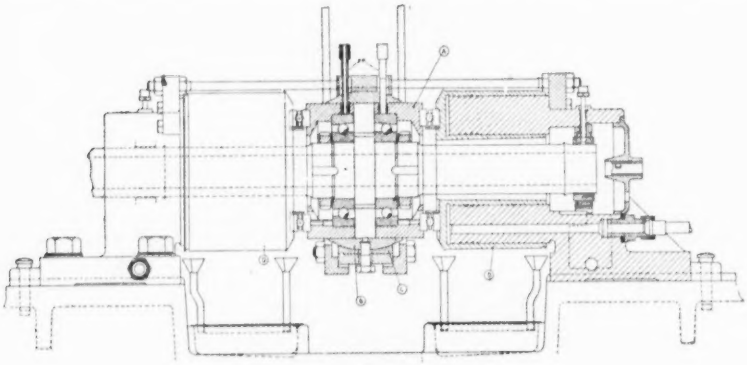

Fig 1

WORKING SECTION OF NO. 1 HIGH-SPEED BEARING MACHINE

high-speed shaft. The outer races of these bearings are fitted into holders *AA*, which can slide within an outer holder *B*, which is turned spherical on the outside to fit and adjust itself within the outer housing *C*. The radial loading system is similar for machines 1 and 2, and can be seen by reference to Fig 2. Radial load (*i.e.*, load in the plane of the bearings) is applied to the bearings via a 20 : 1 ratio single-lever system and a parallel link connecting system. The torque arm is an extension of the yoke of this system. Angular movement of the outer race-housing system does not affect the loading lever, so that friction torque on the outer races can be measured by adding weights to a scale-pan at the left-hand end of the torque arm until it is restored to the horizontal, this condition being checked by observation of a scribed line on the arm through a fixed telescope. All connexions in this linkwork arrangement are by hardened steel knife

edges. Referring again to Fig 1, thrust load is applied to the test bearing holders by two annular pistons *DD* loaded by oil pressure, produced by a small reciprocating pump. An air bottle and a hydraulic accumulator are fitted in the pipe-line to eliminate pulsations and regulate oil pressure respectively. In the first development, it was hoped that the loading pistons would float on their oil films and produce no restraint to the angular movement of the bearing housings, but as this did not happen, ball thrust bearings were inserted between the pistons and the bearing holders (these bearings do not rotate, but merely permit the test bearing housings to float freely). The shaft is artificially heated by an electric heater inserted along the axis of the hollow high-speed shaft, and the bearing temperature is usually measured arbitrarily by two thermocouples, passing through the lead-in tubes *FF*, and pressed into contact with the highest point of each of the outer races. Mist lubrication was effected, for the majority of the tests, through two tubes entering the housings at 45° to the vertical, with their nozzles directed axially at the cages of the bearings.

The bearings supporting the high-speed shaft are white metal-lined self-aligning plain bearings. These bearings, each of which carried the same radial load as each test bearing, performed their function completely satisfactorily throughout the whole of the investigation. A gantry over the test section of the machine supports a lever which can be coupled via a swinging link to the housing (Fig 2). This lever is loaded so that when it is coupled to the housing the net (radial) load on the latter is zero. The lever can be brought into action by rotation of the handwheel seen in Fig 2, and this permits the machine to be started and stopped under zero load, thus protecting the supporting bearings. The rig is driven by a speed-controlled DC motor through an adapted gearbox from an aircraft engine supercharger, which was used because of the difficult supply position of gearboxes.

Torque measurement is effected by adding weights to the torque arm scale-pan, but, as the torque so measured includes the moment of the arm itself, the torque measurement is made, in practice, by reversing the machine and computing half the difference of the two measured torques *i.e.*, forward and in reverse. The capacity of the machine is :—

Radial load . . .	600 lb/bearing
Thrust (axial) load . .	2000 lb/bearing
Speed range . . .	7000 to 30,000 r.p.m.

No. 2 High-speed Machine

This machine is illustrated in Fig 2. It is, in general, similar in design to No. 1 machine, with the following modifications.

The hydraulic thrust loading system has been replaced by a four-lever system in which each of two pairs of levers forms a " nutcracker " system forcing the bearing housings together. The fulcra of the levers are just above the housing and the lower ends are loaded by a calibrated spring. The lever ratio is 6 : 1. The main advantages of this arrangement are that the thrust races between the loading point and the bearing housings have been eliminated, and also, the net horizontal reaction on the baseplate is zero. To ensure uniform distribution of load on the housings, a thrust ring has been inserted on each face of these with the two knife-edge seatings

for the thrust levers on its outer face, and, on its inner face, three balls bearing on a cone, a groove, and a flat, respectively, spaced at 120° apart on the outer face of each housing. The capacity of this machine is :—

Radial load	1500 lb/bearing
Thrust load	2000 lb/bearing
Speed range	6000 to 30,000 r.p.m.

No. 3 High-speed Machine

This machine was designed primarily for work on bearings under radial load only. An axial section of the test portion is shown in Fig 3; the

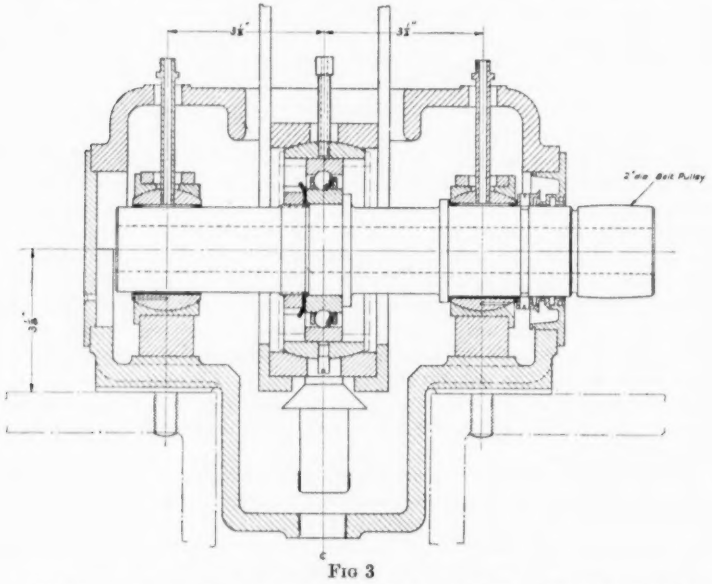

FIG 3

AXIAL SECTION OF TEST SECTION OF NO. 3 HIGH-SPEED BEARING MACHINE

same general scheme as that used for Nos. 1 and 2 machines is adopted, except that a thrust loading system has been omitted, and the high-speed shaft carries only one test bearing. The necessary step-up in speed between motor and high-speed shaft is here obtained by taking the belt drive via a layshaft, the overall ratio of the two pulley systems being 9 : 1. In this machine, artificial heating is effected by injecting the hot exhaust gases from a gas burner into the hollow shaft. The capacity of this machine is :—

Radial load	12,000 lb/bearing
Speed range	5000 to 30,000 r.p.m.

INVESTIGATION OF METHODS AND RATE OF OIL SUPPLY

A superficial consideration of the lubrication of anti-friction bearings might suggest that, because of the predominantly rolling motion involved, no

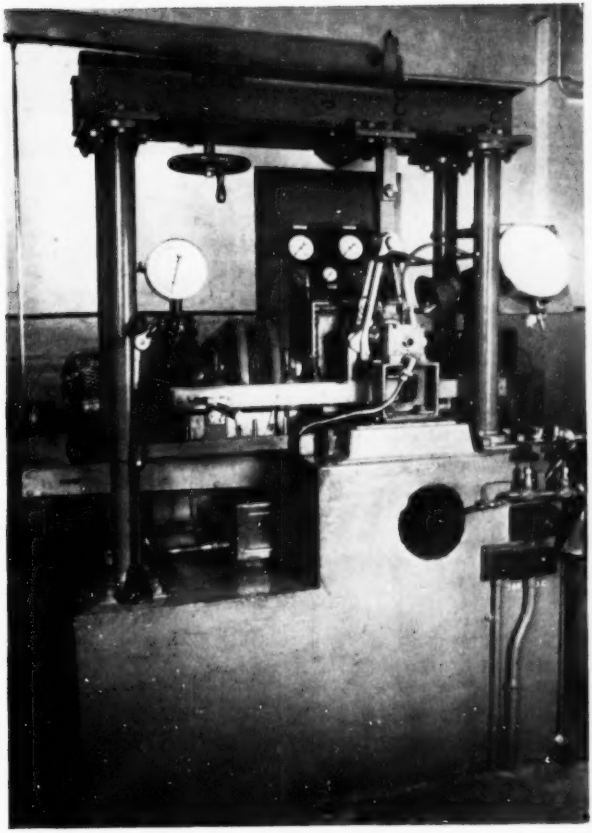

FIG 2

NO. 2 HIGH-SPEED MACHINE

[To face p. 746.

lubricant should be necessary. However, even under nominally pure rolling conditions, *e.g.*, radial load only, some of the rolling elements, being elastically deformed, must be subject also to sliding motion within their areas of contact. Under thrust load, or under combined radial and thrust loads, the motion of the rolling elements becomes more complex and additional sliding motion is introduced. Moreover, in caged bearings there is considerable sliding motion between the rolling elements and the cage, and, in some designs, between the cage and one of the races. There is, therefore, with so many sliding motions, an obvious need for some form of lubrication.

The recognition of the need for continuous lubrication was followed by consideration of the most desirable method of oil supply. Three methods were considered and examined: lubrication by oil bath, by impinging jets, and by oil mist. The first was regarded as attractive from the designer's point of view, and as a means of ensuring an adequate supply of oil at all times, including starting. The second was a convenient and simple method of supplying oil in comparatively large quantities as a possible means of cooling. A danger foreseen in both methods, however, was the possible introduction of high churning losses and, in the latter, the additional danger of possible adverse thermal effects from the impingement of a cool jet of oil on a hot high-speed bearing. Consequently, it was decided to examine, first, lubrication by oil mist; in view of the good results obtained, this method was adopted as the standard method for much other work on design characteristics of bearings. Subsequent experience showed that it compared well with other methods.

Oil-mist Lubrication

The mist was generated in a simple spray device supplied by compressed air at 5 to 10 p.s.i. and by oil fed by gravity; the outlet from the spray was directed towards the balls and cage. Preliminary runs, covering periods of from 50 to 100 hr duration, were carried out on 35-mm bore and 2-inch bore ball bearings under radial loads ranging from 115 to 500 lb/bearing and thrust loads ranging from 30 to 1000 lb/bearing. During this work it was found possible to reduce the oil feed from $1\frac{1}{4}$ to $\frac{1}{4}$ pint/hr/bearing with no apparent deleterious effect, and the latter figure was used in most of the subsequent work. A more critical series of experiments was then carried out to determine, if possible, the optimum rate of supply of lubricant by oil mist under various conditions of bearing load and speed. The details of these are given below :—

(a) *With Radial Load Variation*

(i) Bearings—2·04-inch bore single row ball bearings (extra light type).
Speed—17,750 r.p.m.
Load—Radial, 250 to 750 lb/bearing; thrust, 30 lb/bearing (constant)—the manufacturer's recommendation for radial load operation.
Oil feed—Varied from 3 to 5 pints/hr/bearing to 0·07 pint/hr/bearing.
Lubricant—DTE turbine oil supplied as mist.
No artificial heating of the bearings.

(ii) Bearings—2-inch bore single row ball bearings (light type).
Speed—10,550 r.p.m.
Load—Radial, 250 to 1500 lb/bearing; thrust, zero.
Oil feed—Varied from 3 to 0·07 pints/hr/bearing.
Lubricant—" 620 " oil supplied as mist.

Measurements were made of friction torque and of steady running temperature; the latter are plotted against oil feed in Fig 4. The variation

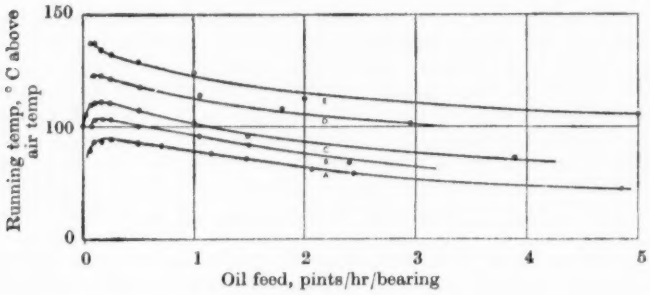

FIG 4

EFFECT OF OIL FEED ON RUNNING TEMPERATURE, 2·04-INCH BORE BALL BEARINGS, EXTRA LIGHT TYPE, RADIAL LOADING

Lubricant, DTE turbine oil; speed, 17,750 r.p.m.; axial load, 30 lb/bearing; radial loading—A, 250 lb; B, 375 lb; C, 500 lb; D, 625 lb; E, 750 lb.

of friction torque with oil feed within the range examined was very small; average results are given in Table I.

TABLE I

Variation of Friction Torque with Radial Load at 17,750 *r.p.m.* (2·04-*inch bearings*)

Radial load, lb	Friction torque/ bearing, lb-inch	Coefficient of friction *
250	0·70	0·0028
375	0·72	0·0019
500	0·75	0·0015
625	0·90	0·0014
750	1·00	0·0013

* Calculated by referring torque to shaft surface.

The measured values of steady running temperature plotted against oil feed are shown in Fig 5, and average values of friction are given in Table II.

TABLE II

Variation of Friction Torque with Radial Load at 10,550 *r.p.m.* (2-*inch bearings*)

Radial load, lb	Friction torque/ bearing, lb-inch	Coefficient of friction *
250	0·70	0·0028
500	0·80	0·0016
750	1·00	0·0013
1000	1·20	0·0012
1250	1·43	0·0011
1500	1·70	0·0011

* Calculated by referring torque to shaft surface.

(b) *With Thrust Load Variation.* To determine whether the variation of temperature with oil feed, using radial loading, was representative of the interrelation of these two quantities in general, a series of tests was carried out in which radial load was nominal (being that due to the weight

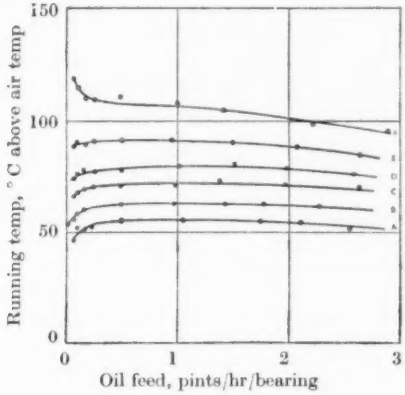

FIG 5

EFFECT OF OIL FEED ON RUNNING TEMPERATURE, 2-INCH BORE BALL BEARINGS, LIGHT TYPE, RADIAL LOADING

Lubricant, "620"; speed, 10,550 r.p.m.; radial loading—A, 250 lb; B, 500 lb; C, 750 lb; D, 1000 lb; E, 1250 lb; F, 1500 lb.

of the bearings and housings), and thrust load was varied over the range 100 to 1000 lb. Typical test conditions were as follows :—

Bearings—2-inch bore single row ball bearings (light type).
Speed—10,550 r.p.m.
Load—Radial, 39 lb/bearing; thrust, 100 to 1000 lb/bearing.
Oil feed—Varied from 3 to 4 pints/hr/bearing to 0·07 pints/hr/bearing.
Lubricant—"620" oil supplied as mist.

Fig 6 gives a typical selection of the curves obtained by plotting running temperature above air against oil feed.

Having shown that oil feeds as low as 0·07 pints/hr/bearing were satisfactory, a further test was made on the 2·04-inch bearings, in which the oil feed was reduced still further down to 0·007 pints/hr/bearing; in terms of actual measurement this was 2 drops/min/bearing. The speed and thrust load were, as before, 17,750 r.p.m. and 30 lb respectively, whilst radial load was 500 lb/bearing. The results are shown as a continuation of the left-hand side of curve C, Fig 4. The bearings ran satisfactorily and without apparent deterioration for 30 hours at the lowest feed.

Finally, tests were made to determine the general behaviour of bearings, operating under different conditions, after completely cutting off the oil supply—as might occur during aerobatics.

In the first case, two 2-inch bearings, similar to those used in the previous

tests, were run under the following conditions, until a steady temperature was attained :—

Speed—10,550 r.p.m.
Load—Radial, 500 lb/bearing; thrust, zero. } Quoted as a typical gas turbine condition.
Lubricant—" 620 " oil supplied as mist at a rate of ¼ pint/hr/bearing. The lubricant was then shut off completely.

Temperature and friction remained steady for 80 minutes, then both began to rise at a rapidly increasing rate, and the bearings squeaked violently. The machine was stopped just as seizure was about to occur. On examination, it was found that balls and races were very hot but apparently undamaged, but scoring was evident in the pockets of the bronze cages.

A second test was made on a similar pair of bearings under the same conditions, with the exception that the radial load was 39 lb/bearing and

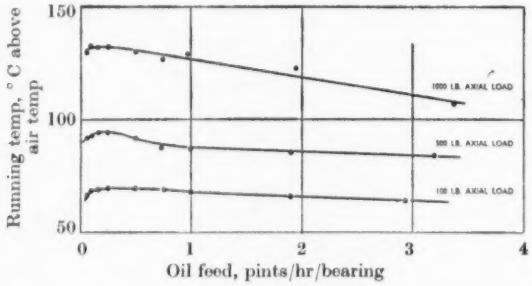

FIG 6

EFFECT OF OIL FEED ON RUNNING TEMPERATURE, 2-INCH BORE BALL BEARINGS, LIGHT TYPE, AXIAL LOADING

Lubricant, " 620 " oil; speed, 10,550 r.p.m.; radial load, 39 lb/bearing.

the thrust load 500 lb/bearing. Very soon after the shut-off of lubricant, bearing temperature and friction began to rise at an accelerating rate, and within 5 minutes the machine had to be stopped to prevent seizure.

A third test was made on a pair of 2-inch ball bearings, of different manufacture from those mentioned above, as follows :—

Bearings—2-inch bore ball bearings (extra light type).
Speed—17,750 r.p.m.
Load—Radial, 160 lb/bearing; thrust, 30 lb/bearing } Quoted as a typical gas turbine condition.
Lubricant—DTE turbine oil supplied as mist at a rate of ¼ pint/hr/bearing.

Bearing temperatures became stable at 117° C. When the oil supply was shut off the bearing temperature dropped about 2° C in the following 5 minutes, remained constant for the next few minutes, then began to rise at a rapidly increasing rate. After 13 minutes from lubricant shut-off the machine began to slow down rapidly. The machine was switched off and it came to rest violently. On examination it was found that one bearing was very rough in its motion, several balls were torn on the surface, and there were two comparatively large pits in the outer race.

The following observations may be made on the results obtained with oil mist lubrication.

The values of coefficient of friction shown in Tables I and II are of the same order as obtained at much lower speeds, and vary in approximately the same way with changes of load. The variation with oil feed, when supplied in the form of a mist and varying in quantity by a factor of almost 1000, is very small. The two maximum values of friction torque quoted, 1·00 and 1·70 lb-inch, are equivalent to a horse-power loss of approximately 0·28 h.p., which may be regarded as a negligible loss in a gas turbine.

The curves of Fig 4 show that, under radial loading conditions, the temperature rise of the extra light type bearings at a feed of ¼ pint/hr/bearing is never more than about 25% higher than that at 3 pints/hr/bearing; in the case of the light type bearings (Fig 5) temperature rise, except at the highest load, is almost independent of the rate of oil supply within the range investigated. Under thrust loading (Fig 6), the same general relationship holds.

An interesting characteristic is evident in nearly all the curves shown in Figs 4, 5, and 6, namely, a maximum temperature rise at an oil feed of about ¼ pint/hr. This is presumably due to two conflicting effects of a lubricant in a ball bearing, cooling and churning. However, with the very small supply rates involved in the foregoing experiments, neither of these effects is very large, and consequently the maxima are not very pronounced.

Although there appears to be some advantage, in terms of reduced operating temperature, in using oil feeds up to the order of 3 to 5 pints/hr under heavy loads, the tests have shown that it is possible to reduce the oil feed to quite minute quantities without any apparently adverse effects. With the oil feed shut off completely, the bearings continue to operate satisfactorily for an appreciable period under considerable radial load, but under thrust load there is practically no safe time interval.

Oil Bath Lubrication

To determine the optimum nominal bath level for oil bath lubrication, an adjustable weir was fitted in the bottom of the inner spherical housing, the level of the top of this weir being adjustable to each of three positions: the level of the top of the lowest ball in each race, a level halfway up the lowest ball, and the level of the inner edge of the outer race. Adequate drainage was provided and, when the bearings were stationary, oil could flow through them at the fixed level and be discharged.

Two series of tests were carried out, one at a fixed radial load and variable speed, and one at a fixed speed and variable radial load. The running data for the two series were :—

(*a*) Bearings—2-inch bore single row ball bearings (light type).
Load—Radial, 500 lb/bearing; thrust, zero.
Speed—Variable, 6000 to 15,000 r.p.m.
Lubricant—" 620 " oil.
Oil feed—¼ pint/hr/bearing by metering pump.

(*b*) Bearings—As in (*a*) above.
Load—Radial, variable, 0 to 1500 lb/bearing; thrust, zero.
Speed—10,000 r.p.m.
Lubricant—" 620 " oil.
Oil feed—¼ pint/hr/bearing by metering pump.

The oil feed and pumping method adopted were in simulation of a practical design of gas turbine bearing supply system.

The results for the two series of experiments showing temperature rise plotted against speed and load are given in Figs 7 and 8 respectively. Values of friction torque varied correspondingly.

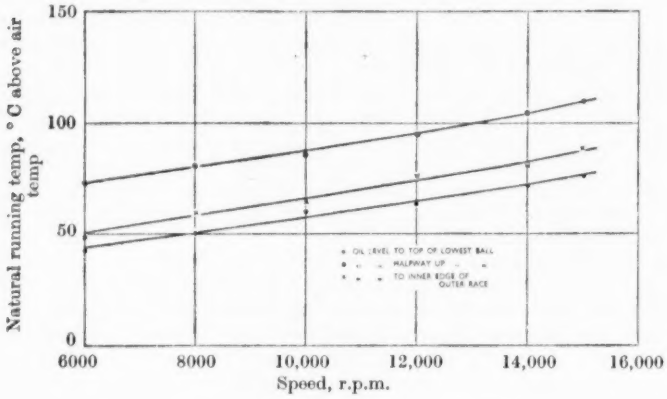

FIG 7

OIL BATH LUBRICATION, VARIATIONS IN OIL LEVEL, 2-INCH BORE BALL BEARINGS
Radial load, 500 lb; lubricant, " 620 " oil.

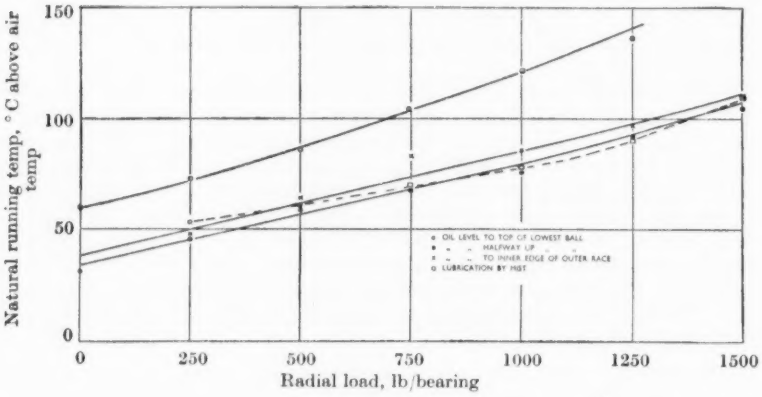

FIG 8

OIL BATH LUBRICATION, VARIATIONS IN OIL LEVEL, 2-INCH BORE BALL BEARINGS
Lubricant, " 620 " oil; speed, 10,000 r.p.m.

It is apparent from the curves that at all speeds and loads there is an optimum nominal oil bath level in the region of the middle of the lowest ball. The results would indicate, therefore, that, in order to avoid excessive churning losses, the level of the oil bath is rather critical and

should lie in the region quoted. Other experiments, with occasional short-term overloads, as occur during aerobatics, confirmed this result.

Comparison of Bath and Mist Lubrication

The conditions of load and speed illustrated in Fig 8 are embraced by tests already carried out with mist lubrication (see p. 747). As an interesting comparison, and ignoring the $5\frac{1}{2}\%$ difference in the speeds quoted, corresponding values from Fig 5 have been plotted in Fig 8 as a dotted line (using the same rate of oil feed of $\frac{1}{5}$ pint/hr/bearing). It may be noted that the bearing runs at the same order of temperature using mist lubrication as it does with optimum-level bath lubrication. As the two series of tests were carried out at different times, however, a stricter comparison was carried out on the same size of bearing under combined (radial plus thrust) loading. The results of this test are given in Table III.

TABLE III

2-inch Bore Single Row Ball Bearings (Light Type)

Lubricant: "620" Oil

Lubrication	Speed 10,550 r.p.m., thrust load 500 lb, radial load 130 lb	
	Natural running temperature, °C	Friction torque, lb-inch
Mist at $\frac{1}{4}$ pint/hr/bearing	127	1·50
Bath at $\frac{1}{4}$ pint/hr/bearing (level one-third up lowest ball)	140	1·56

A similar test was made on 55-mm bore ball bearings of American manufacture, running under a different set of conditions and simulating the operating conditions of a type of gas turbine then under development; the results are given in Table IV.

TABLE IV

55-mm Bore Single Row Ball Bearings (Extra Light Type)

Lubricant: DTE Heavy Medium Turbine Oil

Lubrication	Speed 17,750 r.p.m., thrust load 30 lb, radial load 160 lb		Speed 17,750 r.p.m., thrust load 30 lb, radial load 500 lb	
	Natural running temperature, °C	Friction torque, lb-inch	Natural running temperature, °C	Friction torque, lb-inch
Mist at $\frac{1}{4}$ pint/hr/bearing	110	0·90	117	1·05
Bath at $\frac{1}{4}$ pint/hr/bearing (level one-third up lowest ball)	122	1·00	132	1·32

A more exhaustive comparison was then carried out of the variation of friction and running temperature over a range of speeds at constant load, and over a range of radial loads at constant speed. For these comparisons, the 55-mm bearings were chosen, as they were of lighter construction

than the 2-inch bearings, and it was envisaged that they would withstand the high speeds better. The running conditions were as follows :—

Bearings—55-mm bore ball bearings.
Load—Radial, 130 to 750 lb/bearing; thrust, 30 lb.
Speed—6000 to 21,000 r.p.m.
Lubricant—DTE heavy medium oil.
Oil feed—¼ pint/hr/bearing, by mist, and ¼ pint/hr/bearing, bath.

The results of these tests are shown in Figs 9 and 10.

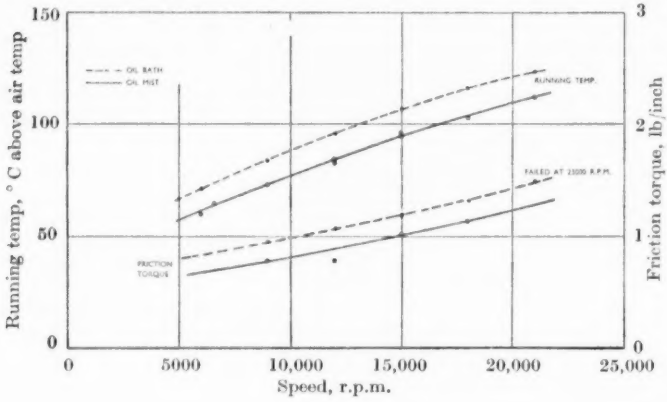

Fig 9

55-MM BEARINGS. COMPARISON OF OIL BATH AND OIL MIST LUBRICATION AT VARIOUS SPEEDS

Oil, DTE heavy medium oil; radial load, 500 lb/bearing; axial load, 30 lb/bearing.

It is evident from Tables III and IV and from Figs 9 and 10 that mist lubrication gives lower values of friction torque and natural running temperature than lubrication by the oil bath method. It will be noted that the curves of Fig 10 tend to converge while those of Fig 9 are roughly parallel. This indicates that, at the higher loads, the greater churning losses in the bath-lubricated bearing form a smaller proportion of the total friction loss (Fig 10), whereas when speed is varied at constant load (Fig 9) the churning losses increase with speed, maintaining a nearly constant difference between the curves.

In the case of the aircraft gas turbine, where bearing friction losses of the magnitude recorded with either system of lubrication are relatively unimportant, the oil bath system may be advantageous by ensuring the presence of oil at the instant of starting. On the other hand, if it is necessary to reduce operating temperatures in every way possible, the oil mist system would be preferable.

Oil Jet Lubrication : Large Feeds

Because of engine developments involving higher bearing loads and, in some cases, larger bearings, with consequent greater heat generation, it became necessary to consider the possibility of using oil, at relatively

high rates of flow, as a coolant for ball and roller bearings. High rates of flow would also have the advantage of reducing the risk of oil freezing in exposed pipelines at low temperatures, and thus obviate the need to use very low viscosity oils with their disadvantages at high temperatures. They would also be more convenient for inclusion in common oil circulating systems, then under consideration, for turbine reduction gearing, auxiliary drives, and bearings.

Although the previous experiments on oil feed variation had shown no great change in either running temperature or friction, the range of flows explored was very small in relation to those which could conveniently be used in a circulating system. Under the latter conditions, however, it was

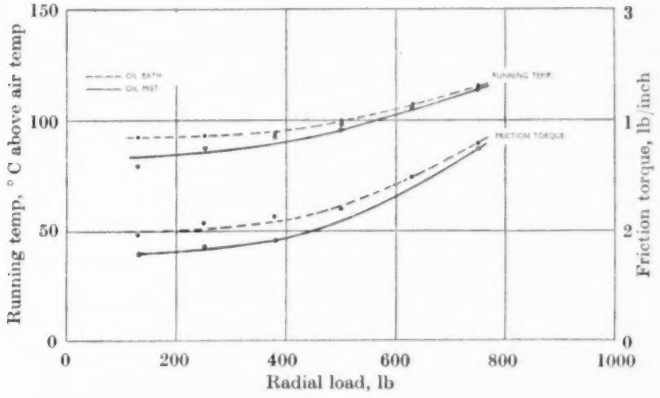

FIG 10

55-MM BEARINGS. COMPARISON OF OIL BATH AND OIL MIST LUBRICATION AT VARIOUS RADIAL LOADINGS

Oil, DTE heavy medium; axial load, 30 lb/bearing; speed, 15,000 r.p.m.

problematic whether the conflicting effects of cooling and churning would result in a net increase or decrease in bearing temperature and friction. Accordingly, a series of experiments was made with oil fed as a single " solid " jet to each bearing at rates of flow up to 10 pints/min.

The arrangement consisted of a $\frac{1}{4}$-inch bore pipe placed so that the jet of oil emerging from it was at right angles to, and impinged directly on, the side of the cage and the balls at the top of the bearing. The end of the pipe was about $\frac{3}{8}$ inches from the bearing. The housing was arranged so that adequate drainage of the oil from both sides of the bearing was provided, and it was impossible for a pool of oil to accumulate around the bearing. This latter precaution had been shown to be necessary by the experiments on oil bath lubrication.

The first test was carried out under the following conditions :—

Bearings—2-inch bore single row ball bearings (light type).
Speed—10,000 r.p.m.
Load—Radial, 2500 lb; thrust, zero.
Oil feed—Varied from 1 to 10 pints/min/bearing.
Lubricant—" 620 " oil.

The oil inlet temperature was kept constant and at as low a value as was consistent with the capacity of the oil cooler. The main bearings of the test machine were also supplied from the same sump, and the tem-

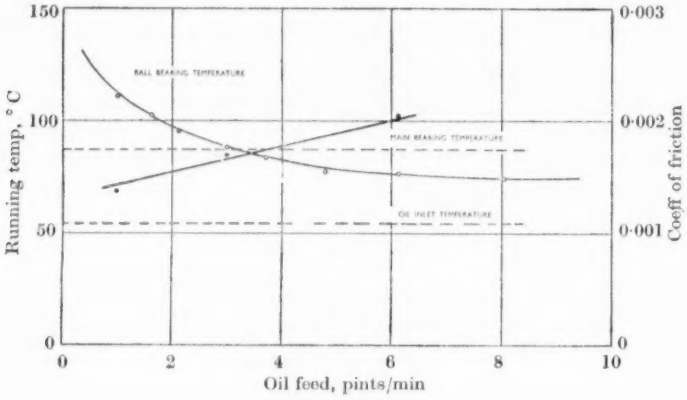

FIG 11

INFLUENCE OF LARGE OIL FEEDS ON RUNNING TEMPERATURE AND FRICTION OF A 2-INCH BORE BALL BEARING

Lubricant, " 620 " oil; speed, 10,000 r.p.m.; radial load, 2500 lb.

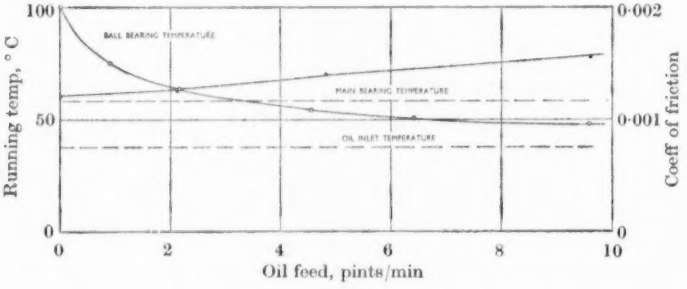

FIG 12

INFLUENCE OF LARGE OIL FEEDS ON RUNNING TEMPERATURE AND FRICTION OF A 2-INCH BALL BEARING

Lubricant, 50/50 mixture of DTD 44D and tractor vaporizing oil; speed, 10,000 r.p.m.; radial load, 2500 lb.

perature of these was also maintained constant. In Fig 11 are plotted the running temperature and coefficient of friction against oil feed.

A second similar test was carried out with a very low viscosity blend of oil, namely, a 50/50 mixture of DTD 44D and tractor vaporizing oil, under the same conditions of load and speed. The results are plotted in Fig 12. Due to the low viscosity of the lubricant, both oil inlet tem-

perature and main bearing temperature could be maintained at a lower level than was possible in the previous experiment.

A third test was made on a roller bearing over a corresponding range of oil feed, the running conditions being as follows :—

Bearing—2-inch bore single row caged roller bearing (extra light type).
Speed—18,000 r.p.m.
Load—Radial, 1000 lb; thrust, zero.
Oil feed—Varied from 1 to 6 pints/min.
Lubricant—" 620 " oil.

The results of this experiment are plotted in Fig 13.

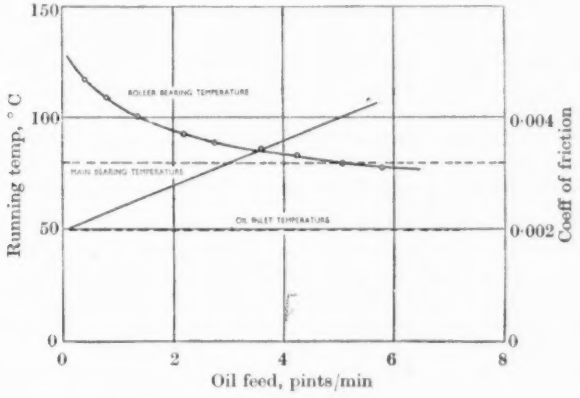

FIG 13

INFLUENCE OF LARGE OIL FEEDS ON RUNNING TEMPERATURES AND FRICTION OF A 2-INCH BORE ROLLER BEARING

Lubricant, " 620 " oil; speed, 18,000 r.p.m.; radial load, 1000 lb.

Using the 2-inch ball bearings, an investigation was made to determine whether the point of impingement of the jets on the bearing was an important factor governing the performance of the bearings. Four positions, additional to the one previously used, of the jet at the top of the bearing were tried as follows :—

1. With the jet directed approximately on the inner race.
2. With the jet directed approximately on the outer race.
3. With the jet directed on the cage, but at an angle of about 45° to the plane of the bearing in the direction of motion.
4. As in 3, but against the direction of motion.

There was very little difference in bearing performance for any of the positions of the oil jet, all running temperatures for one particular rate of oil feed falling within a range of 5° C.

These experiments clearly demonstrate the considerable cooling effect obtained by the simple arrangement of passing large quantities of oil through a jet whose position in relation to the bearing is not critical. It is unnecessary for all the oil to pass through the bearing, and the only precaution necessary is adequate oil drainage from the bearing housing.

Figs 11, 12, and 13 show, for both ball and roller bearings, very considerable drops in temperature at, say, 4 to 6 pints/min oil feed compared with oil mist lubrication. Although the cooling rate (*i.e.*, the slope of the temperature–oil feed curves) decreases considerably at the higher feeds, the gain is still appreciable, in spite of the fact that, over approximately the upper half of the oil feed range, the supporting bearings of the test shaft are running at a higher temperature than the test bearings, and thus, heat, additional to that generated in the test bearings, is being conducted to them along the test shaft.

The increase in internal friction, even at the higher speeds and with the more viscous lubricant, is from most practical points of view negligible, the total loss per bearing being only about 1 h.p. at about 6 pints/min oil feed.

The proportionate increase in friction is about the same as that of oil viscosity due to the lowering of the running temperature, indicating that change of viscosity alone may be responsible for the increased friction, and that churning losses are probably negligible, even under these conditions.

Investigation of the Influence of Lubricant Properties

It is not easy to estimate from analytical considerations the importance of the properties of the lubricant itself in the reduction of friction. Two obvious properties which suggest themselves are viscosity and "oiliness." A hydrodynamic element may exist in the state of lubrication between cage and races, and between cage and rolling elements; on the other hand, these members may be largely lubricated under boundary conditions, whilst the lubrication of the areas of contact between the rolling elements and the races would be expected to be under boundary conditions. An investigation was therefore undertaken in which the viscosity and "oiliness" of the lubricant were varied, using different conditions of radial and thrust load.

Viscosity

In order to cover a sufficiently wide range of viscosity, the oils given in Table V were used.

Table V

Lubricant	Viscosity (centipoises) at: 70° F	140° F
Servo fluid . . .	35	8·3
"620" oil . . .	222	28
DTD 109	830	72

In addition, a fourth oil, consisting of "620" as base with an addition of 5% rape oil, was used to give a preliminary indication of the effect of the presence of an "oiliness" additive in the mineral oil. The viscosity of this mixture was not appreciably different from that of the plain oil. All the tests were made on one pair of bearings to eliminate bearing variations. Repeat tests were made at various times to check up on the constancy of the behaviour of the bearings.

Radial Load and Speed Variation. Two series of runs were made according to the data below :—

	1st Series	2nd Series
Bearings	2-inch bore single row ball bearings (light type)	
Load	Radial, 0 to 1500 lb/bearing; thrust, zero	Radial, 500 lb/bearing; thrust, zero
Speed	10,000 r.p.m.	6000 to 15,000 r.p.m.
Lubricants	As above	
Oil feed	¼ pint/hr/bearing by mist	

The results of these tests are given in Figs 14 to 16. Figs 14 and 15 show the variation of natural running temperature with load and speed

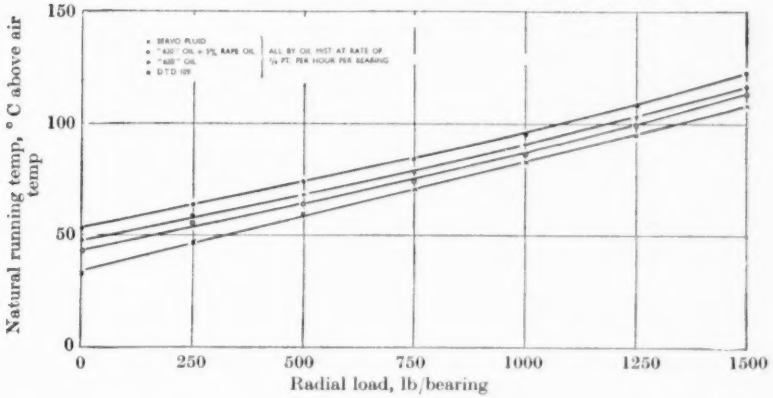

FIG 14

EFFECT ON NATURAL RUNNING TEMPERATURE OF VARIOUS LUBRICANTS—2-INCH BORE BALL BEARINGS

Radial loading, 0–1500 lb; speed, 10,000 r.p.m.

respectively, and Fig 16 shows the variation of friction torque and coefficient of friction with load at a speed of 10,000 r.p.m., the variation with speed being inappreciable.

Thrust Load Variation. A pair of 2-inch bearings, of the same dimensions as those used in the previous series, was used for a similar series of tests under thrust loading. The running conditions were as follows :—

Bearings—2-inch bore single row ball bearings (light type).
Load—Radial, 128 lb/bearing; thrust, variable 0 to 875 lb/bearing.
Speed—10,000 r.p.m.
Lubricants—As above.
Oil feed—¼ pint/hr/bearing by mist.

(The radial load of 128 lb/bearing, being the load due to the friction and radial load lever system of the test machine, was necessary in order to enable friction torque measurements to be made.)

The results of the tests are shown in Figs 17 and 18, where natural running temperature and friction are plotted against load.

From Figs 14 to 16 the following points may be noted. In spite of the considerable differences in the viscosities of the lubricants used, the differences in natural running temperature are relatively small, the maximum variation being of the order of 20° C, although a consistent small rise with

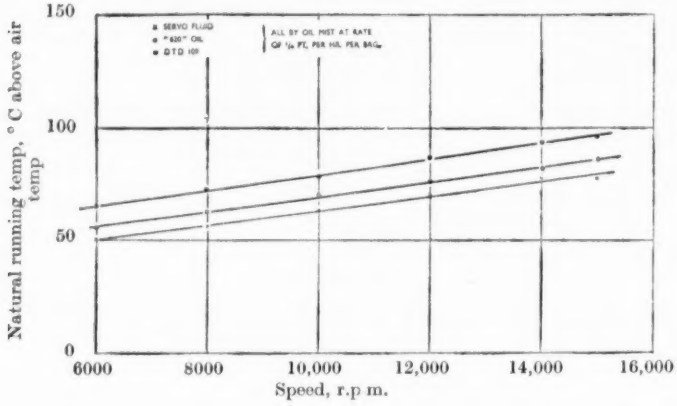

FIG 15

EFFECT ON NATURAL RUNNING TEMPERATURE OF VARIOUS LUBRICANTS—2-INCH BORE BALL BEARINGS

Radial load, 500 lb/bearing; speed, 6000 to 15,000 r.p.m.

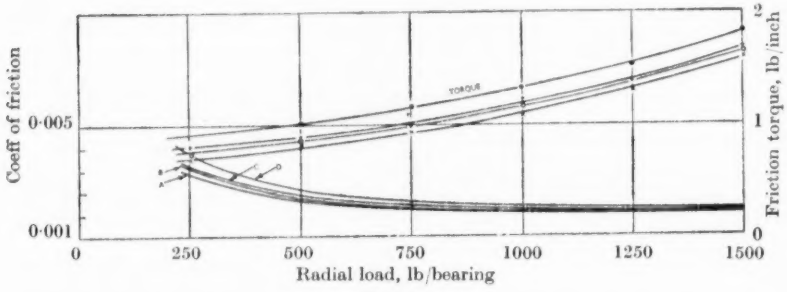

FIG 16

2-INCH BORE BALL BEARINGS. FRICTION AT NATURAL RUNNING TEMPERATURES WITH VARIOUS LUBRICANTS

Radial loading, 0 to 1500 lb/bearing; speed, 10,000 r.p.m.; oils—A X Servo fluid; B 0 "620" + 5% rape; C + "620"; D DTD 109. All by oil mist at rate of ¼ pint/hr/bearing.

viscosity is apparent at all loads and speeds. A slightly greater effect is noticeable at low loads, as would be expected if viscosity is of any significance, since the viscosity differences become less with increasing temperatures.

It is difficult to draw any definite conclusions about the quantitative

effect of viscosity from the friction results (Fig 16). On the one hand, the differences in friction torque resulting from a change from Servo fluid to oil DTD 109 are about 30 and 15 per cent at 250 lb and 1500 lb radial load respectively, from which it might be inferred that, although viscosity

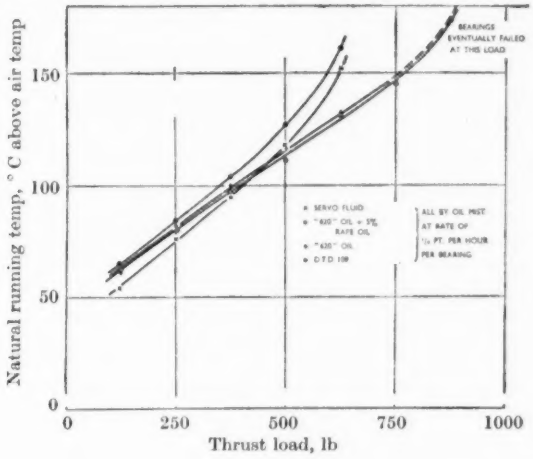

FIG 17

2-INCH BORE BALL BEARINGS. EFFECT ON NATURAL RUNNING TEMPERATURES OF VARIOUS LUBRICANTS

Thrust loading, 0–875 lb/bearing; constant radial load, 128 lb/bearing; speed, 10,000 r.p.m.

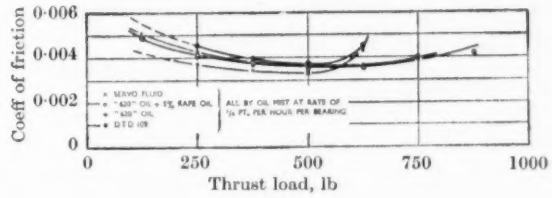

FIG 18

2-INCH BORE BALL BEARINGS. FRICTION AT NATURAL RUNNING TEMPERATURE WITH VARIOUS LUBRICANTS

Thrust loading, 0–875 lb/bearing; constant radial load, 128 lb/bearing; speed, 10,000 r.p.m.

differences are many times greater, viscous or hydrodynamic conditions exist in part. On the other hand, changes in friction torque with speed at constant load are negligible, and, although some allowance should be made for reduced operating viscosities at higher speeds, due to increased temperatures, it might be argued that viscous effects must also be virtually negligible.

However, from a practical point of view, it is evident that under radial

load the variation in viscosity does not produce any marked variation in internal heat generation, and as, for instance, in a gas turbine, the internal heat generation forms only a proportion of the total heat reaching the bearing, the effect of viscosity from this point of view can be regarded as negligible.

The results of tests under thrust load (Figs 17 and 18) show in general the same features as have already been noted under radial load, with the exception that, above a load of 500 lb/bearing, the " 620 " oil, both doped and undoped, exhibits some superiority over the other two oils. It is argued that at high temperatures it may be expected that any previously existing hydrodynamic conditions tend to devolve into boundary conditions, and, in the case of the doped oil, the presence of an " oiliness " additive then delays the turn-up of the temperature–load and friction–load curves. This argument leads to the postulate that as the undoped " 620 " oil gave a performance comparable to that of the doped oil, the base oil itself possesses some intrinsic " oiliness."

It appears from these tests under radial and thrust load that in neither case does fluid film friction form a substantial part of the total friction, and that no great significance need be attached directly to viscosity. Also, although no definite conclusion can be drawn about the importance of the " oiliness " of lubricants for these applications, there is a clear indication that it may be a significant property, particularly under thrust or combined loads or high temperature conditions.

Accordingly, further investigation was made, using a base oil of known inferior boundary lubrication properties in conjunction with additives, the effects of which were also separately assessed under known boundary conditions.

Effect of Oiliness Additives

The running data for these tests were as follows:—

Bearings—2-inch bore single row ball bearings (light type).
Speed—12,000 r.p.m.
Load—Radial, 0 to 380 lb/bearing; thrust, 380 to 0 lb/bearing (both to give constant arithmetical sum).
Lubricants—DTD 44D; DTD 44D + 5% oleic acid; DTD 44D + ½% dope " X."
Oil feed—By mist at ¼ pint/hr/bearing.

DTD 44D was chosen as base oil for these experiments because its boundary lubricating properties were known to be poor. Oleic acid is often used as a standard laboratory additive of good " polar " properties, and dope " X " was a pure chemical known to have good anti-scuffing and boundary friction properties. The loading conditions were chosen so that the sum of the radial and thrust loads was always constant at 380 lb/bearing. By varying load in this way, the range of possible motions between the elements of a bearing would be covered, and, incidentally, the opportunity provided of checking the belief, then current, that the heat generation of a ball bearing was a function of the arithmetic sum of the radial and thrust loads. Repeat tests were carried out after each run with the compounded oils to check on any possible drift in behaviour but the performance was found to be substantially constant. The results of these tests are plotted in Fig 19.

As an outcome of this test, it was considered advisable to carry out kinetic boundary friction tests with each of these oils on surfaces prepared from an actual bearing. Two sets of tests were made :—

(*a*) with a ball on a piece of race steel;
(*b*) with a ball on a piece of bronze cage.

During these tests, temperature was varied over a range 20° to 150° C. With steel bearing on steel, base oil plus dope " X " was best at all tem-

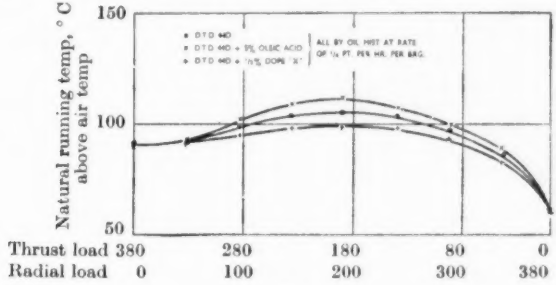

FIG 19

2-INCH BORE BALL BEARINGS. EFFECT ON NATURAL RUNNING TEMPERATURE OF VARIOUS LUBRICANTS

Constant arithmetic sum of loading, 380 lb; speed, 12,000 r.p.m.

peratures and at all speeds, the base oil was next, and the base oil plus oleic acid worst, except at very low speeds. Typical values of coefficient of friction are given in Table VI :—

TABLE VI

Kinetic Boundary Friction Tests : Steel on Steel

Lubricant	Coefficient of friction	
	100° C	150° C
Base oil (DTD 44D) . . .	0·14	0·18
Base oil + dope " X " . .	0·12	0·16
Base oil + oleic acid . .	0·165	0·20

With bronze on steel, the differences between the oils were less marked, and up to 100° C there was no appreciable difference in friction except at very low speeds. At 150° C the base oil was worst and the other two about equal, but, over the speed range examined, the friction of the base oil was falling slightly with increasing speed and the friction of the other two rising slowly with increasing speed, indicating that at still higher speeds the differences, even at this temperature, might be inappreciable.

The results given in Fig 19 show that, except under pure radial and pure thrust loading, distinct differences in bearing performance are obtained with the three oils, the differences being maxima at a ratio of radial to thrust load of about unity. The order in which the oils are placed is the same as when ball and race steel are lubricated by them under kinetic

boundary conditions. Since the three oils are sensibly of the same viscosity, it may be concluded that, over a major portion of the range of operation of lubricated ball bearings, boundary conditions occur to an appreciable extent.

The exact location of the boundary conditions in the bearing is indicated by two considerations. First, it is apparent from Fig 19 that the greatest heat is generated when thrust load is approximately equal to radial load (incidentally demonstrating the error of the belief current at the time regarding the significance of arithmetic sum of loads). Under this condition, as compared with pure thrust or pure radial load, additional slip is imposed on the balls relative to the races, due to the continually changing contact angle of each ball and, hence, ball path radius. Secondly, the effectiveness of the various lubricants in minimizing the heat generated under this condition is related directly to their effectiveness in reducing boundary friction between ball steel and race steel, rather than between steel and bronze from the cage (where no significant differences were observed).

Thus it seems that boundary conditions occur primarily between balls and races, and therefore, lubricants are desirable for ball bearings which have good " oiliness " properties in combination with hard steel surfaces.

The relatively poor performance of the bearing with the oil containing oleic acid, although contrary to expectation and experience, is nevertheless confirmed by the kinetic boundary friction tests on ball and race steel.

Conclusions

The following general conclusions concerning high-speed rolling bearings are drawn from this investigation :—

1. Lubrication by oil mist, oil bath, or oil jet is satisfactory under the wide variety of operating conditions investigated. The only precaution necessary, applying particularly to the oil bath and oil jet methods, is the provision of adequate drainage from bearing housings.

2. The rate of oil supply for satisfactory lubrication can vary over an enormous range, *e.g.*, from one or two drops to several pints per minute.

3. Lubricating oil can be used as a very effective coolant without introducing undue friction losses.

4. Bearings operating under thrust or combined loading are extremely sensitive to an interruption of the oil supply; under substantial radial load, bearings will run safely for several minutes with the oil supply cut off completely.

5. Viscosity is a property of little significance in the selection of lubricating oils for these applications.

6. The lubricating conditions appear to be predominantly boundary in character, and most critical under combined, and approximately equal, radial, and thrust loading. Consequently, lubricants having good " oiliness " properties when associated with hard steel surfaces are desirable.

Acknowledgments

The authors wish to acknowledge with thanks the permission of the Ministry of Supply (Air) and the Department of Scientific and Industrial Research to publish this paper.

THE INSTITUTE OF PETROLEUM

An Ordinary General Meeting of the Institute was held at 26 Portland Place, London, W.1, on 8 April 1953, Dr E. B. Evans, vice-president, in the Chair.

The General Secretary read the minutes of the preceding meeting, which were confirmed and signed, and the list of members elected since the previous meeting.

The Chairman said: Our paper this evening will be given by Mr W. C. Dickerman, who has had very long experience in the field of petroleum refinery engineering, and has served with the Pure Oil Company, Alco Products, and the Houdry Process Corporation. He is now sales engineer for the Lummus Company in this country.

The following paper was then presented by W. C. Dickerman:

THE PRESENT STATUS OF THE ART OF CRACKING PETROLEUM FRACTIONS

By W. C. Dickerman, Jr.*

Introduction

This paper first shows how the development of the automobile, followed by its wide acceptance, brought about a need for cracking. It then reviews the various thermal processes and comments on their present status. Catalytic processes are discussed next, with special attention to cracking. The final section presents typical processing schemes, showing how selections will vary with product requirements.

Petroleum Product Requirements Since the First World War

Trend of Consumption in the United Kingdom

Fig 1 shows the annual consumption of main products in the United Kingdom for the thirty years 1921 to 1951.[1-3] Statistics for 1952, when they become available, will spotlight two distinct trends even further. First to be noted is the sixfold total increase from 3 to 18 million tons. More important, however, is the change in composition.

Fig 2 shows the percentage composition of this tonnage. Already well defined by 1926, the demand for motor spirit continued to expand until the outbreak of the second world war in 1939. Although the total quantity of fuel oil, inland and for ships' bunkers, remained fairly steady, its relative position on a percentage basis declined because of the rapidly expanding consumption of motor spirit.

During and after the second world war the total requirements doubled in quantity, but because of rationing and heavy taxation, consumption of

* The Lummus Co. Ltd.

motor spirit failed to increase as rapidly as that of total fuel oil. On a percentage basis, motor spirit receded to the same status as in 1921. Fuel oil in 1951 enjoyed an even more prominent position than in 1921.

What can be said with respect to the future course of consumption? Although in the U.S. the annual rate of increase appears to be diminishing, this does not seem to be true of Britain and Europe.

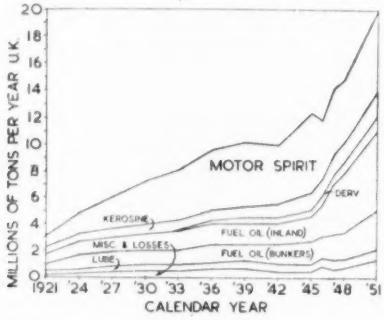

FIG 1

ANNUAL CONSUMPTION OF MAIN PETROLEUM PRODUCTS, UNITED KINGDOM, 1921–51

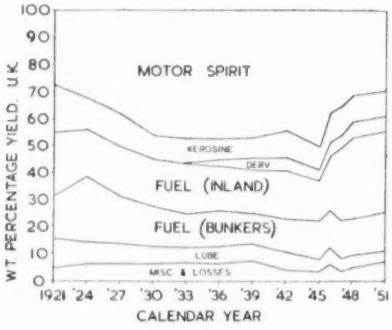

FIG 2

PRODUCT DISTRIBUTION, WEIGHT PERCENT, UNITED KINGDOM, 1921–51

Motor spirit consumption has been suppressed by heavy excise taxes. New automobiles have been channelled into the export market by strict controls, and their sales at home discouraged by a purchase tax of two-thirds of their wholesale value. Because of heavy use of motor spirit in commerce and public transportation, its consumption will increase. The rate will be slow unless changes in taxation promote private motoring.

Lord Ridley, in his report of July 1952,[4] foresees only a limited expansion in coal production over the next ten years. Current statistics for both output and worker productivity bear out his prophecy. Oil, already

without par for Admiralty fuel and for commercial vessels, will probably command an increasing inland market.

A limited supply of coal and heavy taxation of motoring will probably extend the demand for fuel oil as compared to motor spirit.

Trend of Consumption in the U.S.

Fig 3 shows the annual production of main refined products in the U.S. over the years 1921 to 1951.[5, 6] Again a gigantic increase of more than fivefold over the same thirty-year period is seen.

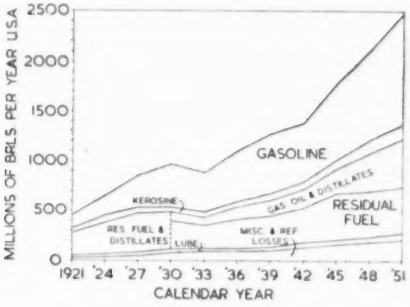

FIG 3

ANNUAL PRODUCTION OF MAIN PETROLEUM PRODUCTS, UNITED STATES, 1921–51

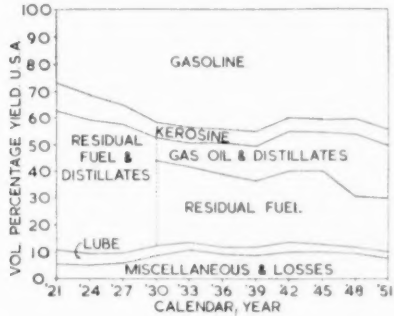

FIG 4

PRODUCT DISTRIBUTION, VOLUME PERCENT, UNITED STATES, 1921–51

Fig 4 shows the percentage composition. The course of the product distribution, as in the United Kingdom, shows the development of the automobile. Motor spirit demand grew rapidly at the expense of distillate and residual fuels. Beginning in 1930, when statistics distinguishing the two first became available, still another trend became noticeable. Distillates have steadily encroached on the demand for residual fuels, while the demand for motor spirit has remained steady by comparison. Two factors are responsible for this shift. Distillate fuels have been receiving increasing acceptance for house heating in areas not heretofore served

with natural gas. Diesel railway locomotives are rapidly replacing steam for both goods and passenger services. This has meant the elimination of an important market for residual fuel oil in those areas lacking coal, and the displacement of coal elsewhere. In the last few years ocean shipping traffic has declined, resulting in further elimination of markets for residual fuel.

Forecasts of demand are closely related to general business activity, so are difficult to make. Informed opinion believes that the total rate of increase in the future will be of the order of 3 to 5 per cent per year instead of the 6 to 8 per cent realized since the end of the second world war. Registrations of motor vehicles continue to expand, but at rates governed more by steel supply than a saturated market. Conversion of railway locomotives (with certain exceptions) from steam to diesel is proceeding as rapidly as engine output permits. These factors will help sustain demand for motor spirit and diesel fuel. Transcontinental pipelines bringing natural gas from the Southwest are being rapidly extended to the Northeast. This gas may slowly but surely displace distillate fuels for house heating there. Sustained demand for all products except residual fuel is thus seen.

Anti-knock Rating of Motor Fuel

ASTM (F-2) octane ratings of both premium and regular gasoline in the U.S. for certain years, as collected and published by the U.S. Bureau of Mines,[7-9] is shown in Fig 5. It can be seen how the second world war

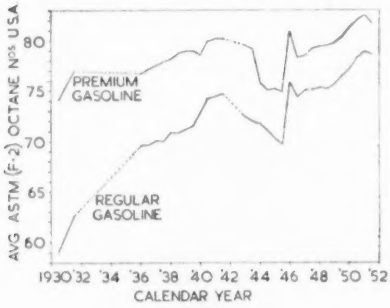

FIG 5

AVERAGE ASTM OCTANE NUMBERS, U.S., FOR PREMIUM AND REGULAR GASOLINE

merely delayed the ever rising trend. Again, hostilities in Korea, and the rearmament programme, have suppressed the steady increase for a time. Since the anti-knock rating of gasoline is one of the principal points of competition, it is certain to rise farther just as soon as temporary depressants, such as shortage of lead and refinery strikes, have passed.

In Britain the return of brands for petrol is certain to introduce octane rating as a point of competition. Since the extra cost of the premier grade of motor spirit is only threepence or fourpence out of a total cost of fifty-three pence, the potential increase in mileage to be had from the higher octane rating is bound to be very significant.

The Pattern of Consumption Has a Far Reaching Effect on Refinery Processing Methods

The extraordinary increase in consumption of petroleum products in the thirty years from 1921 to 1951 has been shown. Of more significance to a discussion of cracking processes are the changes in the relative requirements for the various products.

In both the U.S. and the United Kingdom the tremendous development of the automobile caused a great demand for motor spirit, whereas requirements for fuel oils diminished. In the U.S. the demand for residuals continued to dwindle, but in the United Kingdom it increased substantially.

In both countries war and its economic and other dislocations halted temporarily the call for higher octanes. But it is moving on irresistibly.

In the following sections will be traced the development of cracking as a means to meet these product requirements, and the rise of thermal methods, together with their replacement by catalytic, will be followed.

Thermal Cracking

Early History

Cracking—meaning the conversion of higher boiling oils to lower boiling ones—certainly began with Young's distillation [10] of Scottish shale oil under pressure to increase the yield of kerosine. Similar things were being done in America in the production of "coal oil." It was not until production of automobiles began to increase the demand for motor spirit that it became necessary to augment straight-run naphthas with spirit produced by cracking.

The early developments were numerous and varied, but several processes are worthy of mention in a brief review. The Burton still, developed by the Standard Oil Company of Indiana, was one of the first to be used commercially on a large scale. It worked best on distillate gas oils. Almost at the same time the Dubbs process was evolving. It was able to handle black residual oils successfully. The Cross process, which operated on distillates under pressures of 600 to 800 lb, came along.

Dealing with the coke, which appeared to be the inevitable side product of the cracking reaction, plagued early engineers. The best solution seemed to be in the provision of a reaction chamber, away from the furnace or heating zone, where the reaction could proceed and where the coke—as it formed—would cause the least disturbance.

During the decade 1920 to 1930, commercial operations were expanded to a tremendous scale. At the same time, through study and research, certain fundamental principles evolved, which changed cracking from an empirical art to a science based on established principles.

Perhaps the most significant of these are two: first, the concept of reaction velocity, and the fact that it varies not only with different crudes, but, far more significantly, with the boiling range of the stock to be handled; second, the concept of crack-per-pass, and the fact that there are practical limits, which, as before, vary with the crude source, the boiling range of the stock, whether it has been previously cracked, and, particularly, whether it contains asphalt.

Modern Thermal Cracking Processes

Some Definitions.—Fig 6 presents a diagram showing methods of processing the several fractions into which crude is frequently split. The light benzene is shown as receiving chemical treating only. This is the usual practice, but sometimes it is combined with the low octane heavy naphtha and reformed. Reforming, which by its very name suggests the re-arrangement of molecules, is performed chiefly to improve the octane number of the naphtha, with reduction of boiling range entirely incidental. Cracking is a term applied chiefly, but not always, to the processing of middle distillates for the production of motor spirit. Sometimes the lighter distillates are processed separately from the heavier; sometimes they are handled together. Visbreaking, or viscosity-breaking, as its name implies, aims at reducing the viscosity of heavy fractions, with the production of

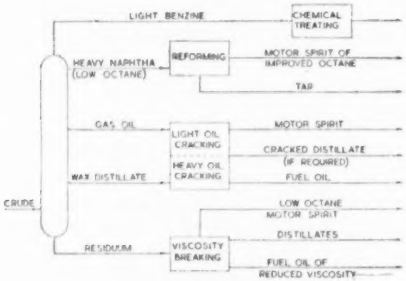

FIG 6

FLOW DIAGRAM OF SELECTIVE CRACKING OPERATIONS

distillates at the same time. If a refiner wishes to produce little or no fuel oil, the residuum is often coked.

Separate Processing of Selected Fractions at Optimum Conditions

Careful and systematic study of the behaviour of the several fractions has shown that processing conditions suitable for reforming the heavy naphtha would coke a residuum. Light gas oil requires a more severe operation than does distillate. Thermal cracking plants processing crude to a high yield of motor spirit usually always have at least two segregated coils, and if reforming is needed to meet anti-knock requirements, it constitutes a third coil.

Fig 7 illustrates a reforming unit, and Fig 8 visbreaking together with heavy distillate cracking. In many instances all of these operations have been combined—with great economy—into one integrated unit as illustrated in Fig 9.

Such combination units have several advantages, all of which promote economy and efficiency :—

1. Each fraction is cracked under conditions most suited to it. The light fractions, which are usually the most refractory, can thus be cracked at high temperatures, producing the highest octane number, and at the maximum economic crack-per-pass.

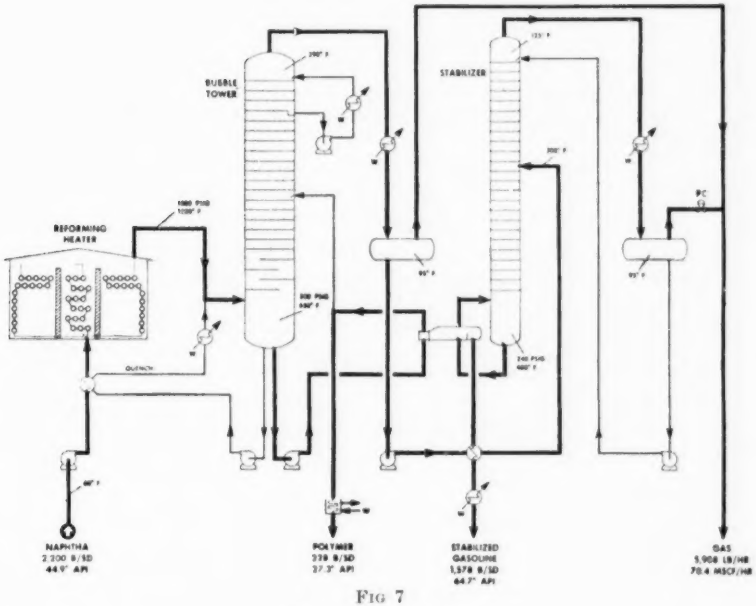

FIG 7

NAPHTHA REFORMING

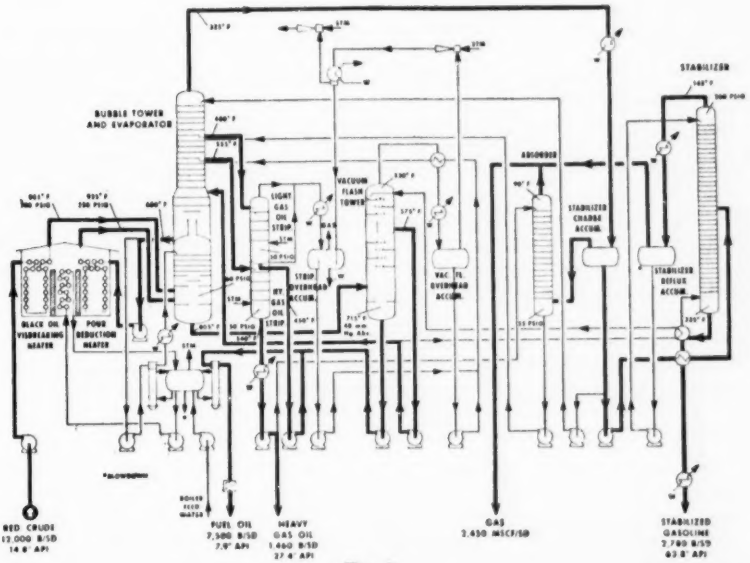

FIG 8

VISCOSITY BREAKING AND POUR REDUCTION

2. The products from the cracking of heavier fractions at the milder conditions required often are lighter distillates suitable for processing in other coils. By integrating these coils into a common fractionation system, the various feed stocks, whether coming from the outside or produced on the unit, will automatically find their way to the proper coil.

3. The heat required for raising these stocks to cracking temperature is always very great. A combination unit makes the best use of it. Often there is enough for integrated distillation of crude.

In certain areas of the world, less fuel oil is needed in proportion to motor spirits and the lighter distillates than in Britain. Often requirements are very small. The refiner can then resort to what is now called delayed coking. Fig 10 illustrates a typical unit. Short residuum, together with a small amount of cycle distillate, is heated to 920° F and introduced to a drum. Vapours pass to a fractionator, but the liquid remains in the drum, in which it slowly reacts to form coke. Two or more drums are always provided, so that while one drum is filling another can be cleared. Highly effective devices have been developed for removing the coke. One of these uses water under high pressure, and the other a boring tool.

Another process circulates coke pellets the size of small marbles. Heavy pitch is sprayed on the hot pellets, producing distillate vapours, and laying down a film of coke like the skin of an onion. The pellets then pass to a drying and heating area, from which they are returned to the reactor. When the pellets reach a certain size, they are removed as product. The process is not yet available commercially.

Thermal Cracking Replaced by Catalytic Units

Perhaps because of the greater need, perhaps because certain earths or clays found in nature were suitable catalysts, catalytic methods were first applied to gas oils and then waxy distillates. Higher yields of better anti-knock spirit were obtained. At first catalytic cracking units—as will be described later—were very expensive, but as improvements were made, they became less costly. Catalytic methods were, therefore, applied first to the premium stocks, such as light gas oils, and then to the more difficult. Thermal cracking units were used to crack catalytic gas oils where required. As costs were reduced, recycling on catalytic units became economic, so many thermal cracking units were dismantled or converted to other services.

Thermal cracking of the middle distillates will probably never become completely extinct, because it is useful in special circumstances, such as very small installations, or to process stocks unusually high in aromatics.

Thermal Reforming Being Replaced by Catalytic Methods

Although several commercial units were built before [11] the second world war, catalytic reforming did not expand rapidly until after 1950. Since, in general, catalytic methods will produce higher yields of higher octane motor spirit than thermal, they are steadily replacing the latter. Many of the thermal units built after the war are still in operation, but as catalytic

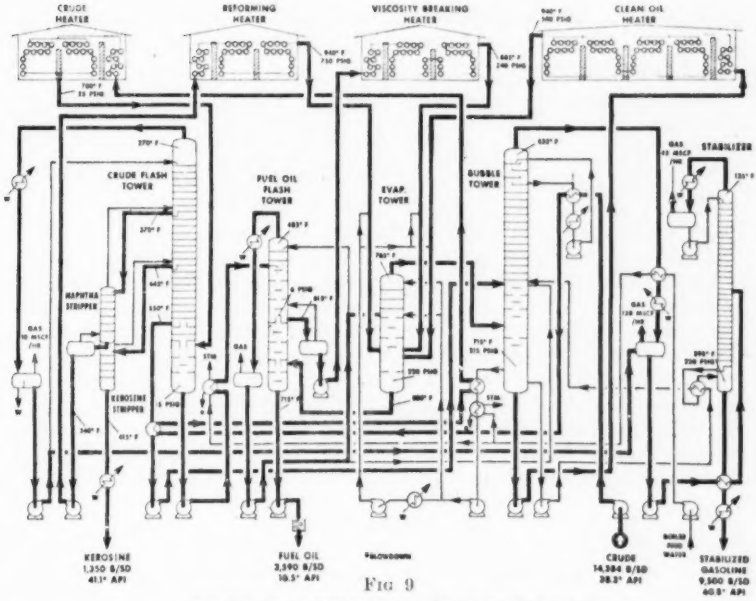

FIG 9

COMBINATION REFORMING AND VISBREAKING

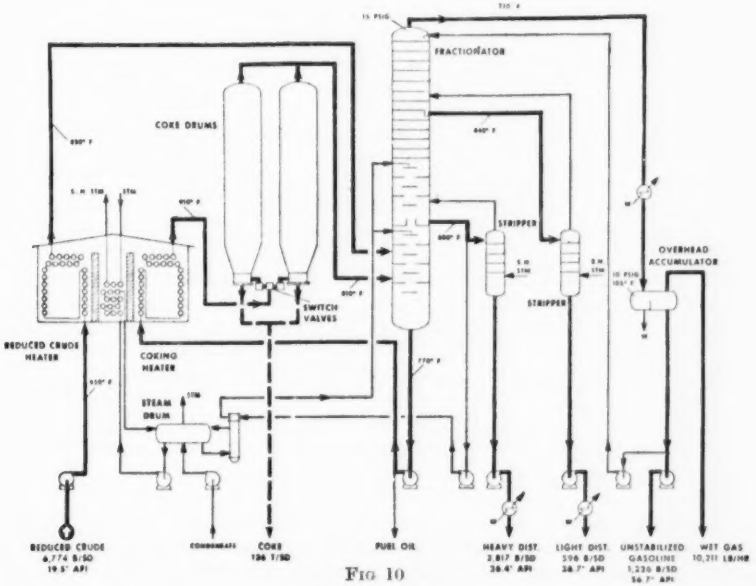

FIG 10

DELAYED COKING

techniques improve and costs come down, the present thermal reformers are sure to be converted or replaced, particularly now that a price has been placed on superior quality in motor spirit.

Although small catalytic reformers have proved to be both efficient and economical in the U.S., it may well be some years before the small thermal reformers, particularly on the Continent, are replaced by or converted to catalytic methods. Much depends on the anti-knock level required for a competitive position.

Thermal Methods Still Used for Visbreaking and Coking

No catalytic methods have been devised as yet for viscosity breaking or for coking. Propane deasphalting has been used for the production of heavy feeds of low carbon residue for catalytic cracking. Higher yields [12] are obtained, but the deasphalted oils often contain components—thought to be heavy metals—which deactivate the cracking catalyst.

Several new delayed coking units are being considered for areas where the coke commands a high price or residual fuel is hard to sell.

Special techniques for the visbreaking [13] of vacuum tar have been developed by a refiner operating in the Mid-Continent region of the U.S. to reduce residual oil yields to a minimum without resorting to coking.

Catalytic Cracking

The Pioneer Stage

As early as 1927, Eugene J. Houdry established the fact that certain naturally occurring earths would promote [14] the cracking of middle distillates into gasoline of high anti-knock rating. The catalyst, however, soon lost its activity due to the formation of coke on it. Houdry showed that, if this coke were burnt off at controlled temperatures, the catalyst would regain its activity. This operation, though simple in principle, was not easy to carry out on a scale sufficiently large to make the method valuable in the petroleum industry.

The design [15] and perfection of a commercial plant required years of hard effort. The first commercial unit with a nominal intake capacity of 2000 b.d. went on stream in Paulsboro, New Jersey, in June 1936. After this, development was rapid, with the result that by 1941, fourteen plants had been put into operation. The process utilized reactors in multiples of three, which went through various operations in sequence. The catalyst did not move, but when the catalyst in a given reactor lost its activity because coke had been deposited on it, the feed was switched to the second reactor. The first reactor was then purged of feed vapours, and regenerated by the introduction of heated air. When the coke had been burnt off, the reactor was purged of combustion gases, and it was ready again for the oil feed.

Many engineering problems were solved. The first industrial gas turbines in the U.S. were driven by the combustion gases, with the power used to compress the air for regeneration. Molten salt in a circulating system was used to carry off and utilize the heat of regeneration. Automatic cycle timers were devised to operate the power valves, which switched the various streams in and out of the reactors at the correct moments. In spite of these efforts, the process remained expensive. Engineers were

intrigued with the benefits of a circulating arrangement, in which catalyst moved continuously from a reactor to a regenerator and back.

The Moving Bed Process

One organization, which had developed a new device for the regeneration of percolation clay used in the decolorizing of lubricating oils, felt it might serve as a continuous regenerator or kiln for spent cracking catalyst. But the regenerated catalyst, a granular solid, must be introduced in some way to a reactor which was filled with hot oil vapours under pressure. If the

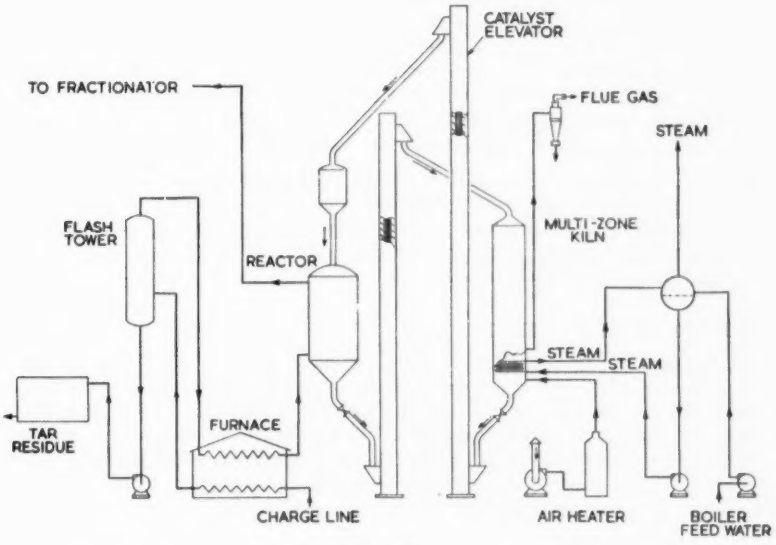

FIG 11

EARLY ELEVATOR TCC UNIT

catalyst was allowed to flow by gravity through the kiln or the reactor, it was necessary to raise it. Bucket elevators existed, but the catalyst was hot.

These problems, and a host of others, were eventually solved.[16] The first Thermofor Catalytic Cracking (TCC) Unit was put on stream in a refinery in Beaumont, Texas, in early 1941. The design used two high temperature bucket elevators, one for spent and another for regenerated catalyst. Flow was by gravity down through both the reactor and through the regenerator. It was soon realized that if catalyst was somewhat larger in particle size than the percolation clay, which had been its antecedent, the vanes installed in the first units could be omitted. This gave the moving solid bed, in which one particle of catalyst rests on and in contact with the other, as the whole mass moves slowly downward in kiln and reactor.

Fig 11 shows an early elevator type unit. Under pressure of the second world war, many installations of this type were made to produce aviation gasoline.

Soon after the war, it was realized the earlier arrangements had several disadvantages.

1. While the mechanical performance of the elevators had been excellent, their limited capacities tended to hold down catalyst circulation rates, particularly in relation to the quantity of the oil charge.
2. If more catalyst could be circulated in relation to a given amount of oil, more of the heat produced in burning coke off the catalyst in the kiln or regenerator could be removed in the form of sensible heat in the catalyst. Not only would this permit the elimination of some of the catalyst cooling coils in the kiln, but this sensible heat of the catalyst could be put to very good use in the reactor in supplying the endothermic heat of reaction, or in vaporizing feed if necessary.

The potentialities of increased catalyst circulation were so great that careful study was made of pneumatic lifts. At this stage a split took place, with the result that two organizations came into the picture. While both have, in essence, made use of the same basic principles, they have applied them in different ways.

The Airlift TCC Process

This process, as developed [17] by the Socony-Vacuum Oil Co., is shown in Fig 12. The reactor is now mounted above the kiln, for gravity flow from one to the other. Regenerated catalyst is elevated by air from the bottom of the kiln to a disengager at the top of the structure from which it flows by gravity to the reactor. The kiln has been changed to annular shape, with one battery of cooling coils subdivided into four layers.

Typical operating conditions [18] are tabulated below :

Catalyst to oil ratio	2 to 5 by volume 2·5 to 6 by weight
Reactor space velocity	1 to 2·5 in volume units per hour 0·8 to 2 in weight units per hour
Reactor temperature	840° to 925° F
Reactor pressure	5 to 10 p.s.i.g.
Catalyst activity	25 to 34 Cat A Index

Feed to the reactor can be introduced as a vapour, a liquid, or a mixture of both. The liquid is sprayed from a nozzle on to the inside of a falling annular curtain of catalyst. The vapour enters separately, and flows downward over the catalyst bed. Usually reduced crude, augmented with gas oil, or wax distillate, if desired, is vaporized in a heater and separated in a flash drum. The overhead vapours pass to the reactor. The hot residuum can then be flashed under vacuum (usually without further heating) to produce additional heavy distillate, which is then condensed and sprayed on to the catalyst as it falls on to the reactor bed.

The process has achieved wide acceptance.[19–21] At mid-year 1952, the licensors reported [18] fifteen units in operation (of which nine were in Socony-Vacuum plants or affiliates) and twenty more units under construc-

tion. Several of these are in Europe, with one in Britain at the Coryton refinery.

A small design,[22] available in two sizes—3000 and 6000 b.d. reactor charge—has been designed and developed by the licensor in collaboration with a firm in Los Angeles, California. The catalytic equipment is erected in a structure resembling an oil well derrick. A unit of this type, with a charge rate of 6000 b.s.d., has been in operation [23] at a small refinery in New Mexico since the fourth quarter of 1951.

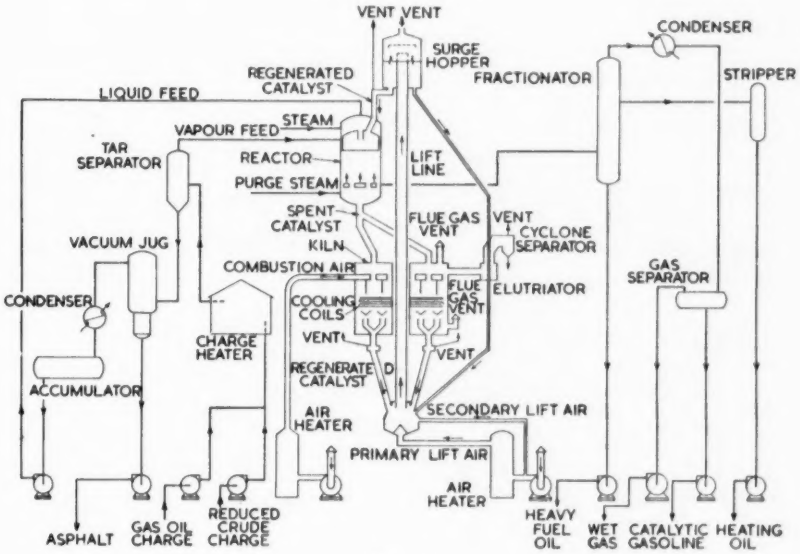

FIG 12

AIRLIFT TCC UNIT

Many of the larger air-lift TCC units have replaced Houdry fixed bed cracking plants.

A plant to manufacture chrome beads is being erected in Germany to supply requirements in Europe.

The Houdriflow Process

This process,[24] like the TCC, has a pneumatic lift, but instead of air, flue gas from the kiln, boosted in pressure by a jet compressor, is used. Again the rector is above the kiln, but is actually in the same vessel. The two zones are separated by seal pipes. Again the kiln has cooling zones.

Typical operating conditions are : [25, 26]

Catalyst to oil ratio . . .	3 to 7 by weight
Reactor space velocity . . .	1·5 to 4 in weight units per hour
Reactor temperature . . .	850° to 925° F
Reactor pressure	5 to 10 p.s.i.g.

The feed injection system to the Houdriflow reactor, as in the TCC, sprays it on to a falling annular curtain of hot catalyst, but is capable of handling a stream in mixed phase, all liquid, or all vapour. This ability eliminates any separating vessel, and simplifies the feed system.

At mid-year 1952 the licensor reported ten units in operation, with only four in a refinery of its parent, the Sun Oil Company. Five more were then in the design and construction stage. One was in another Sun Oil refinery, and two in Europe—one in Germany and one in Belgium.

A flow diagram is shown in Fig 13.

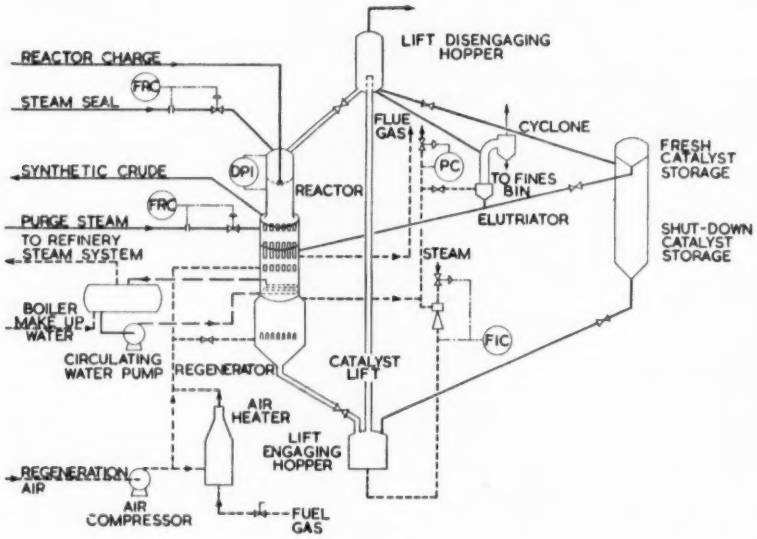

FIG 13

HOUDRIFLOW UNIT

The Fluid Process

With keen realization of the deficiencies of fixed bed methods for catalytic cracking, studies of the effectiveness and utilization of powdered catalyst were begun shortly before the second world war by the Standard Oil Development Company. It was found that vapours would carry the powder along. The next thought was to provide a reaction space, and then separate catalyst from the cracked oil vapours. This was done in a cyclone for separation. The catalyst then accumulated in a hopper. And so Model I of the Fluid Cracking process was born.[27] Three such "Up Flow" units were built.

Further studies of the dynamics of fluidized solids indicated that by proper control of velocities a fairly clearly defined break or level could be established, with vapours very nearly free of catalyst flowing on beyond, and the catalyst remaining to form a turbulent dense phase. It was then

found that fluidized catalyst could be withdrawn from the bed by a standpipe. Fig 14 [27] shows a typical arrangement of the " Downflow " design, termed Model II by some. At the end of the war, fluid cracking units with a nominal capacity of 409,000 b.s.d. had been built and were operating.

Model II incorporated many of the features now almost automatically associated with the Fluid process. Standpipe or bottom withdrawal of catalyst permitted direct liquid injection of feed. It also made it possible to increase economically catalyst circulation to the point where all available heat from combustion of the coke could be utilized in the cracking section.

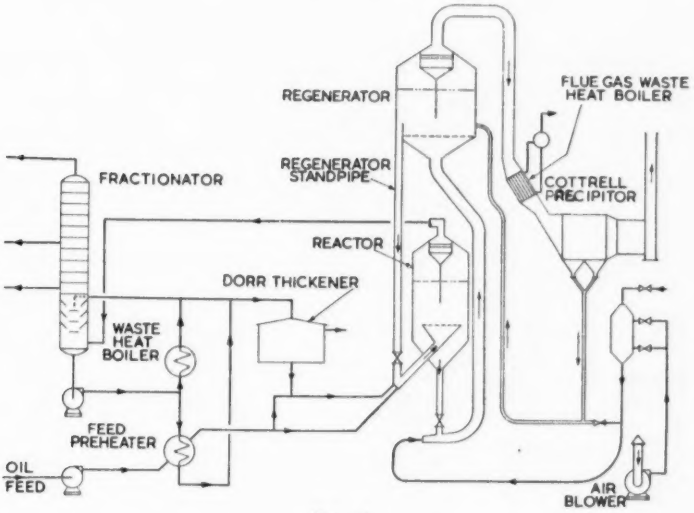

FIG 14

MODEL II FLUID UNIT

This is the well known " heat balance " feature. The regenerators of Model II units were located high in the air, and well above the reactor. Cottrell electrostatic precipitators were used to recover the catalyst fines which passed the cyclones in the regenerator.

Continuous study and development produced, after the second world war, a later design,[28] referred to in some quarters as Model III. It is described as a " balanced pressure " arrangement, with the reactor and regenerator at very nearly the same pressure. The regenerator thus can be almost on a level with the reactor, saving large amounts of structural steel. Improvements in cyclone performance have permitted the elimination of the electrostatic precipitators, and flue gas steam boilers, unless their installation can be justified as a fuel saving measure. A diagram is shown in Fig 15.

A further design,[29] designated as Model IV, incorporates many additional and novel features. The savings in investment cost have been estimated at 25 per cent. The height has been reduced by 45 ft. A further develop-

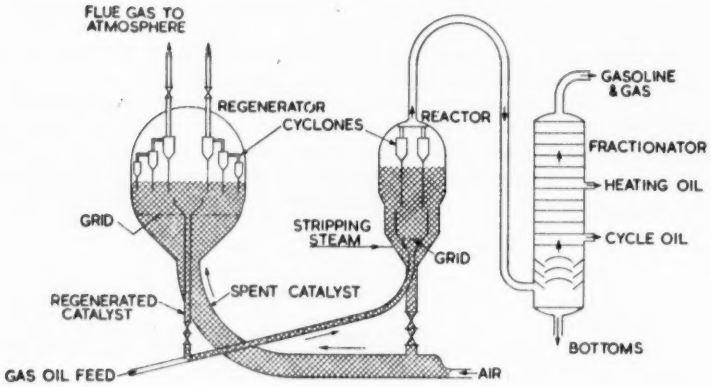

FIG 15

MODEL III FLUID UNIT

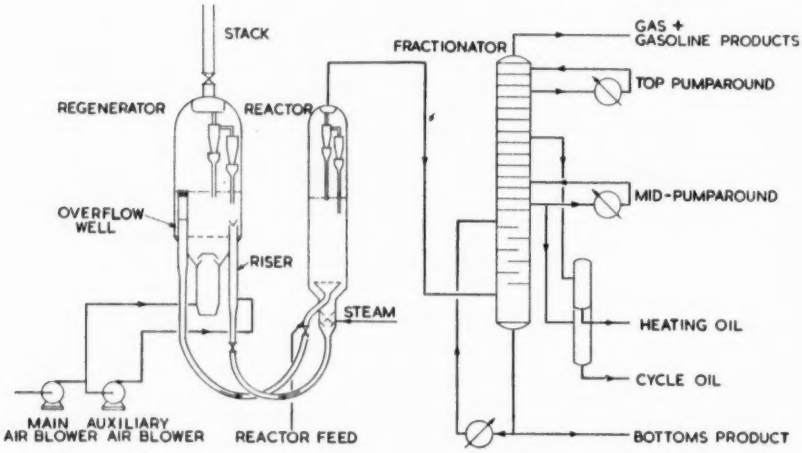

FIG 16

MODEL IV FLUID UNIT

ment is the integration of Fluid cracking with crude distillation, including naphtha reforming. This arrangement reduces refinery handling costs and utilities, among other things. Studies indicate that a small refinery using this technique can manufacture products as economically as a large one utilizing conventional processing sequences.

A diagram of a Model IV Fluid cracking unit is shown in Fig 16.

Universal Oil Products Fluid Cracking Units

In addition to the side-by-side arrangements, the Universal Oil Products Company offers a superimposed design [30] shown in Fig 17, especially suitable for small installations. The heavy structure required in earlier units has been eliminated, together with a general simplification and re-arrangement.

By mid-summer 1952, a total of twenty UOP-designed units have been put on stream since 1947. Fourteen additional units were under construction at that time.

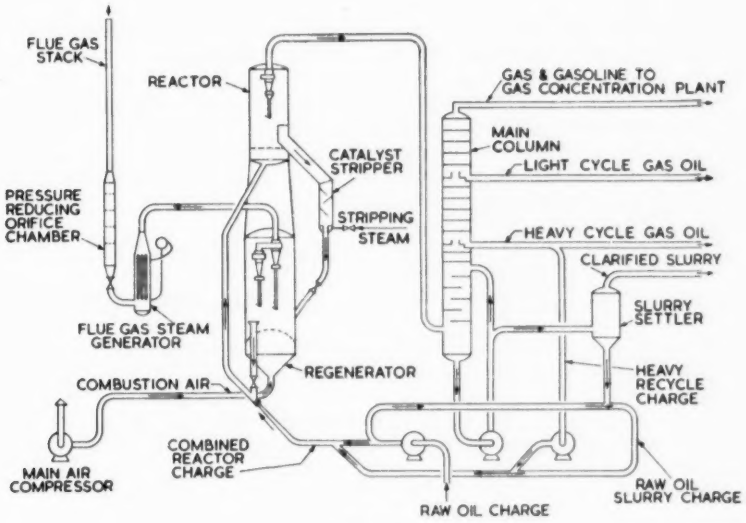

FIG 17

UOP FLUID UNIT

Orthoflow Fluid Cracking Units

Another superimposed design,[31] called the Orthoflow, has been developed by the M. W. Kellogg Company. Its distinguishing feature [32] is the use of internal standpipes for both spent and regenerated catalyst. Plug valves are used for control. Oil feed is introduced through a hollow stem in the valve controlling admission of catalyst from the regenerator bed to the reactor feed line. It is shown in Fig 18.

The licensors have stated that up to mid-1952, three plants [33] had been erected and commissioned. Several others are in the engineering stage.

Yields and Operating Conditions

A recent report [34] by the research staff of the Anglo-Iranian Oil Co. presents correlations of the product yields and qualities for the Fluid cracking of several wax distillate feed stocks derived from crude oils of

four major Middle East fields. While reactor temperature and catalyst to oil ratios varied over normal limits, the range of conversions studied was attained primarily by changing the space velocity.

Summary and Comment

It has been shown that catalytic cracking can now be considered a highly developed art. The principle of continuous operation has proved so efficient that it has very nearly supplanted the earlier fixed bed methods. Two basic techniques have evolved for continuous operation : (*a*) moving solid beds; (*b*) fluidized beds. Two different designs of the former, and several of the latter, are available.

Both techniques use pneumatic methods to transport or circulate the catalyst, but mechanical attrition of the beads or pellets used in the moving

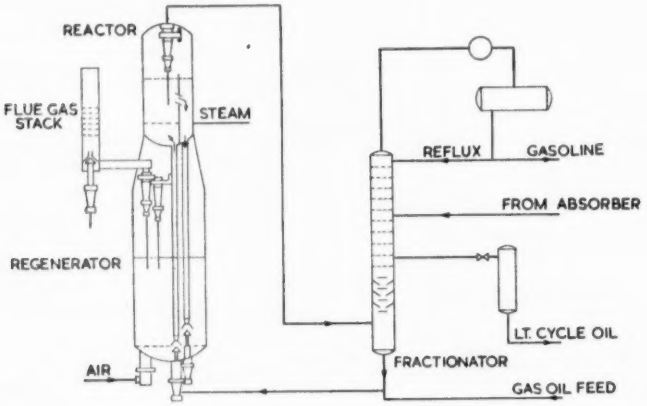

FIG 18

ORTHOFLOW FLUID UNIT

bed processes tends to set economic limits on the catalyst circulation. No moving bed design is yet available which takes up the available heat of regeneration entirely in the catalyst. Yet this is possible with the fluid techniques. Moving bed regenerators all have steam coils, and more heat must be put into the feed as it enters the reactor.

On the other hand, in a turbulent fluid reactor conditions approach the homogeneous. There is always the chance that a given molecule will follow a long path, while another will take a short one. The first molecule will be over-cracked, with loss of yield; and the latter will escape unreacted, or only partially touched. Lower space velocities and higher temperatures are required to compensate.

Furthermore, the purging of occluded vapours and the stripping of adsorbed hydrocarbons, while easy in a moving bed unit, is more difficult in the fluid process. Much effort has been devoted to improving the effectiveness of spent catalyst strippers. In most designs the stripper is

an integral part of the reactor. In another it is combined with the spent catalyst standpipe. A third design [35] uses an entirely separate vessel with its own condenser, to which the spent catalyst is carried by the stripping steam.

Effective stripping improves yields by directing to a useful end hydrocarbons that would be burnt as coke in the regenerator.

Catalytic Reforming

A comprehensive discussion of catalytic reforming processes is outside the scope of this paper. It will include, however, a brief historical review, an outline of the several catalysts, and a tabulation of the processes.

Even before the second world war, it was realized that thermal reforming of naphthas left much to be desired. Yields were poor, even if augmented by polymerization, and the octane numbers attainable did not compare with catalytic cracking. Studies of catalysts consisting of molybdena on alumina indicated that if hydrogen was present in quantity, a considerable improvement in anti-knock could be obtained. It was also found that the catalyst would dehydrogenate naphthenes to aromatics. Polymers and coke were formed, so regeneration was required. Only the fixed bed techniques had been developed at that time, so they were used. Though expensive, the process [36] was eminently successful. It produced by far the major share of the toluene required for explosives and other purposes during the war.

Further research after the war indicated that platinum, a traditional hydrogenation catalyst, in collaboration with other agents, would isomerize both paraffins and naphthenes, and dehydrogenate the latter to aromatics. This new type of catalyst forms so little polymer or coke that it remains active over many months. It is, therefore, used in fixed beds.

Other organizations have acknowledged the coke forming tendencies of molybdena–alumina catalysts and have applied the fluid techniques. Another has perfected a chrome–alumina bead, which it uses in moving bed equipment.

The processes are listed by their catalysts, together with their licensors :

Platinum Type	
Platforming [37]	Universal Oil Products Co.
Catforming [38]	Atlantic Refining Co.
Houdriforming [39]	Houdry Process Co.
Molybdena–Alumina	
Fluid Hydroforming [40]	Standard Oil Development Co.
Fluid Hydroforming [41]	M. W. Kellogg Co.
Chromia–Alumina	
Thermofor Catalytic Reforming [42]	Socony-Vacuum Oil Co.
Cobalt Molybdate	
Hyperforming [43]	The Union Oil Co.

Catalytic reforming is a fully proved method, with seven processes to choose from. The selection will be made on the basis of the stock to be processed, its chemical composition, the severity required, and the size of the installation.

The Application of Cracking to Refinery Requirements

Many different grades of crude oil are produced in the world, and each marketing area has its own requirements, so many combinations are required in a world-wide industry. These generally fall within a range encompassed by a refinery producing large yields of residual fuel, middle distillates, and high quality motor spirit, and another which cannot sell any residual fuel at all, but has heavy demands for high quality motor spirit, high quality diesel fuel, and distillates.

Product demands in certain areas of Europe have been typical of the former, while requirements such as the latter are found in inland areas of the U.S. There, plentiful natural gas has displaced residual fuel oil for industry and power, and the complete change from steam to diesel locomotives on the railways has caused a heavy demand for distillates.

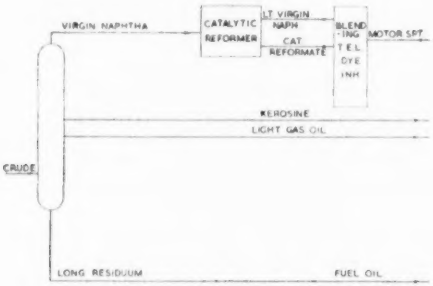

Fig 19

REFINERY PROCESSING SCHEME FOR MAXIMUM FUEL OIL

Maximum Fuel Oil

This processing scheme is illustrated by Fig 19. Crude would be fractionated into a 200° C naphtha, kerosine, diesel oil, and fuel oil bottoms. Since a full range 200° C naphtha seldom has a high enough octane number to make a competitive motor spirit, a reformer—presumably catalytic—would be required to improve the naphtha.

No Fuel Oil

To meet the requirements of no fuel oil, large yields of motor spirit and middle distillates, requires the complex scheme shown in Fig 20. Crude distillation would be as before, and with kerosine going direct to sales. The long residuum (or reduced crude) would go to a thermal coking unit equipped with a vaporizing coil for the residuum as well as the coking coil. Wax distillate would be flashed off the long residuum, with the resulting short residuum combining with a small amount of recycle to produce coke. Low octane heavy naphtha from the coking operations would be reformed catalytically with similar virgin heavy naphtha from crude. Heavy waxy distillate mixed with a similar fraction produced from coking the short residuum would go to a catalytic cracking unit, operated with recycle at

a conversion sufficient so only 300° C distillate is produced in addition to motor spirit.

Intermediate Yields

The two extremes just illustrated are the exception rather than the rule, so the majority of requirements fall between the two. It is in these cases that a thorough understanding of the potentialities of the various processes

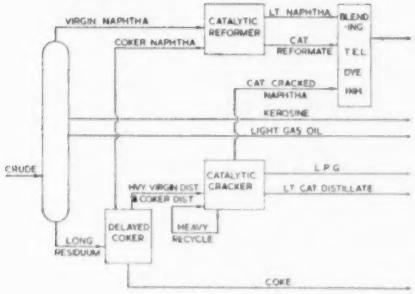

FIG 20

REINERY PROCESSING SCHEME FOR NO RESIDUAL FUEL OIL

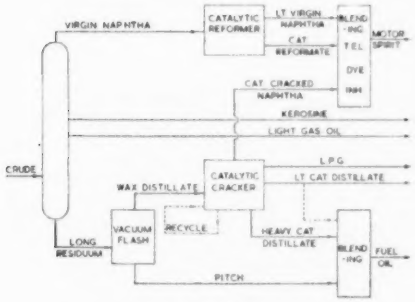

FIG 21

INTERMEDIATE PROCESSING SCHEME

and keen judgment as to their selection and various sizes will provide the flexibility which will permit the refinery output to follow the often fluctuating pattern of market demand. An example is shown in Fig 21.

In these installations it is customary to charge the catalytic cracking unit with wax distillate produced as the fraction between diesel fuel and asphalt. Fuel oil then is produced as a blend of heavy catalytic cycle oil and asphalt. The quantity can thus be varied by adjusting the conversion on the cracking unit. If fuel oil requirements are small, the appropriate

conversion may well be high enough to make recycling desirable. Passing the entire wax distillate through the cracking unit produces the maximum yield of motor spirit, because only degraded cracked catalytic gas oil is blended with asphalt. If the blend of virgin naphtha and catalytic motor spirit does not have sufficient anti-knock rating, reforming, preferably catalytic, is required.

It should be noted that even if the wax distillate charge to the cracking unit contains no fractions in the boiling range of diesel fuel, a substantial production (14 to 18 vol per cent) in this range can be expected. If conversion is moderate, the cetane number of the cracked diesel oil may well be high enough so that a substantial amount of it can be mixed with the virgin cut and still make a blend of competitive quality. If distillate fuel oil, suitable for pressure atomizing burners, is to be made, the percentage of catalytic cracked diesel oil may be even higher.

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Discussion

J. W. Hyde : Mr Dickerman's graphs showed very clearly that in the U.S. there was still an increasing gasoline pattern, but one could notice the increasing demand for middle distillates. These kerosine and gas oil products require high cetane number, good stability, low pour point, and low sulphur-content. The existing cracking processes are limited in production of middle distillates; in fact, coking is probably the only one which offers real possibilities. However, at the moment, like the old catalytic cracking process, this is a semi-batch process. Before one can visualize a combination unit involving a coker, we must see the continuous coker brought to a successful chemical and mechanical engineering state. Can Mr Dickerman tell us a little about developments in continuous coking, and the manner in which the products of continuous coking compare with those from delayed cokers ?

A further point which has not been discussed in this paper is the application of cracking to the production of the olefinic feed stocks required for the manufacture of petrochemicals. In this field, there are two ways of looking at the cracking process. Either the olefinic gases are by-products from cracking processes designed to meet the requirements of the oil industry, or, alternatively, special crackers are installed whose primary function is the production of olefinic gases, with the unconverted highly

aromatic constituents remaining as a by-product to be sold as gasoline. I would like Mr Dickerman to discuss the relative merits of these two approaches to olefinic gases for petrochemical use.

MR DICKERMAN: The so-called contact coker shows a great deal of promise, but it is not yet available commercially. An enormous amount of pilot-plant work has been done, and a small-size commercial unit has been built, and has been operating for some months. When the process is entirely satisfactory it will be offered commercially. In general, one of the principal advantages of the contact, or continuous, coker lies in the continuity of its operation—it is definitely a continuous process. Also, unlike the delayed coker or coil and drum coker, it can handle vacuum pitch with ease. This, of course, means an increased production of heavy vacuum wax distillate, which, since it is undegraded, is a superior catalytic cracking stock. It is expected that the coke produced by this continuous method will be lower in volatile content than that obtained from delayed coking.

The second question pertained to the provision of olefinic gases for the petrochemical industry: whether tail gases obtained from catalytic plants installed primarily to produce motor spirit would be preferable to those from special high temperature thermal cracking units. The most important point is the question of commercial availability, whether the right gases are in the right place at the right time. Demand for petrochemicals after the war increased at a rapid pace, and was strong well before the major refinery construction programme was completed. Since, at that time, there was no other source of olefins, it was necessary to install special high-temperature thermal units which processed heavy naphtha. However, in the eight years since the war, Britain has constructed a major refining industry, including several catalytic cracking units. These, particularly those using the Fluid process, are worthy producers of ethylene and propylene in addition to motor spirit and other distillates. Because of their great cost, there is little doubt that they will be operated continuously. They therefore constitute a dependable and economical supply of light olefins. While existing special-purpose thermal units will probably be run for some years to come, it is likely that new requirements will be met from the tail gas from catalytic cracking units.

DR G. B. MAXWELL: In connexion with the use which Mr Dickerman mentioned of light cracked distillate for blending into fuel oil, would he mind amplifying a little the comparison between thermally-cracked gas oil and catalytically-cracked gas oil for use both in No 2 distillate fuel and also for blending with residuum for the heavier grades of fuel oil, particularly with regard to stability in storage.

MR DICKERMAN: A logical answer to this question requires the discussion of a principle which applies to both thermal and catalytic methods; this is the boiling-range of the feed with respect to that of the light distillate fuel. If the feed is a heavy one, and contains no fractions boiling in the light fuel oil-range, all the cracked light fuel oil made will be the result of a fairly drastic decomposition. On the other hand, if the feed is lighter, and contains virgin fractions in the same boiling-range as light fuel oil, those

fractions will have been subjected to a far less severe conversion process. One must therefore give careful consideration to the boiling-range of the feed, as well as conversion.

For similar conditions of feed and conversion, the light fuel oil from a catalytic unit could be expected to have a better stability because of its greater aromatic content. One could thus blend more catalytic light distillate with a virgin stock and still make a No 2 fuel oil with satisfactory stability.

On the other hand, this very aromatic content of the catalytic stock may introduce problems of compatability in blending a residual fuel oil, particularly if the residual stock is a heavy vacuum pitch. No consumer of residual fuel oil is pleased when sediment deposits on the tubes of his fuel oil heaters or in his tanks. The lower compatability between the aromatic catalytic stock may cause this.

DR MAXWELL : Arising out of that, I would like to ask whether any work has been done to compare the economics of inhibiting, as against refining treatment, when using thermally- or catalytically-cracked gas oils for No 2 distillate fuel, either alone or in blend with straight-run distillate.

MR DICKERMAN : I am very sorry, but I am not informed on those developments ; I understand that a certain amount of work has been done.

MR HYDE : To amplify one of my earlier questions concerning the nature of the products from continuous coking : are their characters identical with those from delayed coking ?

MR DICKERMAN : I am afraid I cannot give you those details. However, since the continuous coking process will handle a short, instead of a longer, residuum, one can count on a far broader cut of vacuum wax distillate.

DR S. E. MILES : I wonder if Mr Dickerman has any ideas on what the future will hold. What are the next steps forward in, say, catalytic cracking ? Will the fluidized bed push out the moving bed or vice versa ? Which is the best, or which is the most profitable, method by which either of those processes will be simplified, cheapened, etc ? He mentions catalytic reforming a lot, and one would assume that he has given up consideration of thermal reforming. Are not the catalytic reformers rather specialized and very expensive, and are the catalysts as stable and as good as they might be ? Are there any chances of getting rid of that, and how many years shall we have to wait before we get a really good process ? Lastly, have we seen the end of thermal cracking altogether, except possibly for coking, or is it going to retain a slight hold ? I wonder what Mr Dickerman's views are.

MR DICKERMAN : I would say the most significant development lies in the direction of catalytic reforming. It had its start before and during the second world war, but its present development took place subsequent to the war, and is continuing at an even greater rate. In years past, many people felt there was a need for a catalytic process, which would not only

produce higher yields, but also higher octane number reformed motor spirit. On the whole, I think that the catalytic reforming process will show even greater promise in that direction.

The construction of catalytic reformers in the United States is growing rapidly. It is unfortunate that this great development did not take place until several years after the war. In Europe there was a need for high octane naphtha, which has resulted in the construction of a number of thermal reformers. I think that it is inevitable that the thermal reforming units will be replaced eventually by catalytic reforming units in refineries of any size. Gradually, these reforming catalysts will be even further improved so as to produce, not only higher octane spirit, but greater yields. I agree that probably a small amount of both thermal reforming and thermal cracking will always be practised.

In so far as cracking is concerned, a lot of work has been done in the direction of producing economic small-size units. Several licensors of the fluid process and the moving bed process have developed, designed, and sold small installations which appear to have been economic. On the other hand, if one is looking for a low investment cost, one certainly can build a thermal cracking unit more cheaply than the catalytic cracking unit. Whether such a decision will be economic in the long run is an entirely different question. It may be better to build a refinery now, even if it is not the best in the world, rather than to wait for the millennium. Certainly, these small units are bound to cost more per barrel in small capacity, but some people believe they have been economic.

C. Vivian Davies: Is it true that it might be preferable to have a number of small units rather than one large unit, in view of the speed with which changes in technique take place, and is there very much difference, economically, between having one large unit in a refinery rather than three or four small ones?

Mr Dickerman: With the possible exception of a very few processes operating at very high pressure, several small units are almost always more expensive than one large unit. In certain cases, however, this added cost can be justified. For one thing, it would enable a refiner to spread his investment over several years. In the case of a rapidly progressing process, he could gain the advantage of later developments on his later units. But the principal advantage is greater flexibility. Most refiners must follow rapidly shifting product demands, both as to variety and as to relative volume. Some refiners do not have a steady supply of one kind of crude, but must take whatever the market affords. Multiple units increase refinery flexibility—but at a price. In most instances the small refiner feels he cannot pay this price, but the large ones often do.

The Chairman: Would you consider that the introduction of the catalytic processes, with their attendant complications, has the overall effect of reducing the flexibility of refineries and refining processes?

Mr Dickerman: That, I think, is a moot point. It is rather hard to separate an inherent advantage in a given process, such as the catalytic,

with the gains from advancing knowledge. Perhaps if the techniques, processing devices, and design methods, which we have now, had been available and had been applied to thermal cracking, its flexibility might have been improved. Certainly, the catalytic techniques, particularly cracking, do show a great degree of flexibility.

MR HYDE : In general, crude oils suffer from either too much carbon or a deficiency of hydrogen. The cost of hydrogen is high, and it may be cheaper to remove coke, but this also supposes that you can get a high price for coke, and that is by no means certain. Does Mr Dickerman consider it possible to visualize a selective de-coking process—for example, a catalytic de-coking process, or one in which the coke is consumed—to provide the heat required for the process, so that it can operate in heat balance ?

MR DICKERMAN : If we eliminate propane de-asphalting as being a non-catalytic method, I find myself unable to cite any catalytic decarbonizing process, unless you can consider a limited application of catalytic cracking to that end as being pertinent. In certain parts of the world, Scuny County in West Texas, for example, crude petroleum is found which has a very low asphalt content. It is therefore considered more economic to build a cracking unit with an oversize regenerator to burn the extra coke produced by what little asphalt there is, rather than to go to the expense of vacuum flashing. Such a cracking unit must often have special provisions for the extra heat produced from the extra coke.

C. I. KELLY : Would Mr Dickerman care to say what he means by " chrome beads " on p. 777 ? Would Mr Dickerman also care to tell us where the catalyst goes in practical operations ? I understand there is a consumption of catalysts in cracking operations, and one reads that the consumption of catalysts is in the order of a fifth of a pound per barrel of charge per stream day, *i.e.*, in a 40,000-b.s.d. unit there are 10,000 lb of catalysts lost ; this is about 5 tons a day. Does it go into the air, into some of the products, or on to the dump, or is it spread over all three ?

Another point I would like to make is this : with the advent of catalytic cracking we have seen an interesting fusion of the techniques of lubricating oil refining with those of cracking. One has to attribute that to the work of Socony-Vacuum in their development of the Thermofor kiln for the regeneration of percolation clay and the possibility of transferring that technique into the TCC process.

The author has not mentioned an interesting process, devised by Dr R. K. Stratford and his team in the Imperial Oil Co, Canada. Stratford uses the spent filter-cakes from the lubricating oil section of the refinery ; these are pugged into the cracking charge-stock and the mixture pumped through a tubular heater of a (modified) thermal cracking plant. Apparently, there is sufficient activity in the activated earth, after lub oil contacting, to give the catalytic cracking effect in the tubes and produce an improved high-octane gasoline. At the end of the system, the spent fuller's earth cakes from the filter-presses, now coke-covered, are cycloned out of the

liquid stream, and, I believe, steamed, and taken to the tip in a fairly oil-free state. If that procedure and process could be developed and more widely used, it could help many lubricating oil refineries with the disposal problem centring on filter-press cakes. I wonder whether there is any possibility of improving this technique and using it more widely in order to solve the problem lubricating oil refineries are now facing, namely, that of the effective and cheap disposal of their filter-press waste-product. If so, the catalytic cracking section of the refinery would, in a sense, be repaying the lubricating oil section a debt it owes to the latter.

Mr Dickerman: The first question asks for a definition of "chrome beads." In the early days of moving bed cracking units, the catalyst was made by pelleting active earths mined in certain places from natural deposits. In their early form these pellets did not have sufficient mechanical strength. In order to produce a stronger catalyst, as well as to obtain other advantages, synthetic methods were devised. A plastic silica–alumina gel was extruded into a non-reacting liquid bath of proper specific gravity at such a rate that the stream broke up into droplets. These individual particles, due to the forces of surface tension, assumed a sphere-like shape, and were called beads. Later, it was discovered that the addition of a small amount of chromia, or oxide of chromium, would accelerate regeneration. The new product has been named "chrome beads."

In all catalytic cracking processes there are catalyst losses; also, at times withdrawals are made from the operating inventory of seasoned catalyst to permit replacement with new in order to maintain activity. By catalyst addition, I mean the total input, whether to make up for losses, or to replace de-activated catalyst.

In the early days catalysts were not as resistant to temperature as they are now. Occasionally, therefore, if temperatures in a regenerator became too high, de-activation took place. It was then generally advisable to withdraw some of the inventory and to replace it with new, in order to raise the average activity. This is not often necessary now.

Also, even now, certain heavy feed stocks contain heavy metals or nitrogen, which often act as poisons or de-activators. Withdrawals in these special instances may be necessary.

Almost all additions, at the present time, are to replace losses due to mechanical breakage of the catalyst particles. In fluid units the particle size resulting from this breakage is so small that the undersize particles escape with the regenerator flue gas. Fortunately they usually stay suspended, and so do not constitute a nuisance to the neighbourhood. On moving bed units, a special device, usually called an elutriator, is provided to purge the circulating inventory of fines. The particle size is larger, and the catalyst is available in regenerated form, so the rejected fines are often used in lubricating oil refining.

Mr Kelly refers to the suspensoid process. Although it appears to be a worthy one, it has not, on the whole, received very widespread acceptance. Perhaps the principal reason is the cost of removing the spent catalyst from the residuum. If in the near future new methods are developed for this, the suspensoid process may become more popular.

MR KELLY: Does any catalyst get into any of the liquid products of the moving bed and fluid operations?

MR DICKERMAN: If the operator of a moving bed unit maintains it well and keeps his working inventory properly purged of fines, very little catalyst will find its way into the reactor effluent.

On the other hand, many, but not all, fluid unit operators find a steady but small amount of catalyst in the reactor effluent. Being non-volatile, it ends up in the fractionator bottom product, which is then clarified or decanted, and the slurry containing the concentrated catalyst returned to the reactor.

THE CHAIRMAN: Mr Dickerman has discussed fully the history and developments of cracking, and has also ventured some predictions into the future—a much more difficult thing to do. We must thank him, not only for his presentation but for the extremely able and informative way in which he has answered a lot of difficult questions.

(The vote of thanks was heartily accorded.)

THE INSTITUTE OF PETROLEUM

An Ordinary General Meeting of the Institute was held at 26 Portland Place, London, W.1, on 13 May 1953, Mr E. J. Sturgess in the Chair.

The General Secretary read the minutes of the preceding meeting, which were confirmed and signed.

The Chairman said: The paper this evening is being presented by Mr E. A. Reynolds and Mr V. F. H. Samson, and follows a similar paper, given at the Institution of Mechanical Engineers by James Bright, on how American industry is attacking the materials handling problem.

Mr Samson is with the Development Division of the Anglo-Iranian Oil Co. Ltd. and is specializing in mechanical handling on the refinery, process, and maintenance side. Mr Reynolds, who may be better known for his work on standard tanks and tank design, deals with mechanical handling on the marketing side of The Shell Petroleum Co. Ltd.

The following paper was then presented by E. A. Reynolds and V. F. H. Samson:

MECHANICAL HANDLING IN THE PETROLEUM INDUSTRY

By E. A. Reynolds * (Fellow) and V. F. H. Samson † (Associate Fellow)

Introduction

Materials handling has received much publicity in recent years, both in the technical and popular Press, as an aid to increased productivity. Therefore, it would be in the general interest to review the position within the petroleum industry and to suggest improvements.

Materials handling has been defined in one report of the Anglo-American Council on Productivity as the rationalizing of handling and movement by reducing them to a minimum, while mechanical handling is considered to be a part of the problem along with plant layout and process machinery design.

The present paper is confined to mechanical handling, partly because this is a more than sufficient field to cover in the space available, and partly because the need for and objects of rationalization are clearly shown by the study of the equipment available and the methods of use.

The movement of unrefined and of finished products has always been by pump and pipeline, and it is fair to say that the oil industry as a whole has been perhaps the foremost exponent of mechanical handling in its intricate processes. Whenever a product has to be moved, either during refinement or to the container or even direct to storage tanks, and in some cases customers' tanks or tankers, this movement is most efficiently and economically carried out by pump and pipeline.

This covers a very wide field, and mechanical handling is therefore

* The Shell Petroleum Co. Ltd. † Anglo-Iranian Oil Co. Ltd.

confined to the movement of component materials, packed products, and their containers, and the handling of plant for maintenance purposes.

Handling equipment is not necessarily complicated or costly; the drum or barrel is a piece of handling equipment by reason of its shape. It can be rolled easily, and rolling hoops developed in its design combine this feature with body stiffening. However, even this simple operation of rolling by hand is becoming outmoded and replaced by fork lift truck handling.

On the refinery side the manufacture of petroleum products is obviously already very highly mechanized, but there is still much scope for increasing productivity and reducing cost, not only in packed products but in bulk also, by reducing the " down " time of plant for maintenance.

Present methods are considered in some detail, but the mechanical handling industry is very alert, and improved equipment and methods are being evolved rapidly. Therefore, in the conclusion the authors give their views on such future trends of development as can be seen or would appear desirable.

Account of Present Conditions

Refineries

Handling problems in a refinery largely centre around maintenance, the movement of process materials, and the handling of finished products other than by pipeline. Much has already been achieved in the use of modern mechanical equipment.

Overhauls, whether intermediate or major, involve the handling of many pieces of equipment and include the withdrawing of heat exchanger tube bundles, the removal and replacement of pumps, motors, compressors, and the contents of distillation columns.

Many of these articles may be difficult to handle by reason of their position, such as safety valves at the top of distillation columns, or by reason of their weight and general make-up, such as tube bundles.

A most important question in the provision of handling gear for maintenance duties is whether it should be permanently installed or be brought to the site when required. While each case must finally be decided on its merits, in general permanent gear is justified for any routine job which would otherwise require rigging effort. There are many jobs which can be done with mobile equipment, but it may not be possible to employ it if the area has not been " gas freed " for a major overhaul. Thus, there are borderline cases for which the only guide is the comparison of the cost of installing permanent gear with the estimated cost of the rigging effort required.

It is important that permanent gear be included in the plant in the design stage, when its cost will be a minimum. A ton of structural steel erected costs roughly £90, which is equivalent, if written off over ten years, to about a week's work a year for one man. It can save many times this amount on any overhaul.

For pump houses and similar places, the handling of pumps and motors can as a rule most efficiently and cheaply be done by a lifting frame on wheels which can be placed over the unit provided the load is not greater than about 2 tons. Beyond this the combined weight of load and frame makes it difficult to move and manœuvre. The alternative is built-in

lifting beams extending to a point where the load can be deposited on to a truck or stillage outside the house if necessary.

The need for flameproofing seriously affects the use and design of any mobile equipment used within the refinery. There is, at present, only one small diesel tractor available with Buxton approval for its flameproofing equipment; two fork lift trucks, also diesel driven, have gone part of the way to meet Buxton requirements. The alternatives are electric power, with its undesirable trailing cables, or compressed air. While the latter restricts movement somewhat by the necessity for flexible hose, damage to the hose is not attended by any danger from sparking.

Compressed air is normally available within the plot area of refinery units. Its fundamental inefficiency as a source of power is outweighed for this sort of application by its safety and convenience.

It cannot be too strongly emphasized that the greatest single factor in assuring efficient plant overhaul is good access, both from the nearest road and within the unit itself. No amount of planning can overcome the handicap of bad access, nor can lifting and handling equipment show more than a fraction of its potential economy.

Access (bridges where required over pipe tracks) is necessary for fork lift trucks, mobile cranes big enough to employ a 90-ft jib, and special gear for picking up and removing the largest tube bundles and electric motors.

Access ways from the nearest road into the plant should be not less than 12 ft wide, and bridges should be of at least 25 tons capacity. If drains and cable trenches cannot be avoided in the plot area they should be provided with covers which can withstand wheel loads of the order of 12 tons or distributed loads from crawler tracks of 1·25 to 1·5 tons/sq. ft.

Headroom under elevated pipe tracks on the unit should be at least 14 ft for mobile cranes to gain access to the centre of the plot and 10 to 12 ft elsewhere.

For vertical heat exchangers the capacity of the lifting gear should be not less than twice the weight of the tube bundle, to allow for jamming caused by fouling. Exchangers grouped together are best served by an overhead travelling crane, the runway of which should extend far enough to allow of bundles being lowered to ground level clear of the surrounding structure.

Permanently installed handling gear is not necessary for horizontal bundles up to about 8 ft above the ground if there is access for a portable "A" frame. Above this height lifting beams are desirable; they must extend far enough to allow the bundle to be pulled clear of the shell.

Each overhead beam should have two runners and blocks, the outer to support the bundle as it emerges from the shell and the inner to carry the whole of the bundle weight, together with slings, etc. Efficient supporting slings are essential if individual tubes are not to be damaged. The load must be spread over a large area and a degree of flexibility introduced.

In the removal of back end covers and bonnets weights up to $\frac{1}{2}$ ton may be involved and, if the labour saved by installing bundle lifting gear is not to be lost, rigging must be avoided. Generally the built-in lifting beams can be extended back far enough to do this job and one of the chain blocks used. Otherwise a separate beam or davit is indicated.

Tube bundles are normally removed by pulling from some fixed point. This usually involves the provision of some additional structure and applies

undesirable horizontal loads of several tons to the exchanger and its supports, including the feet of the shell. This may cause shell distortion, and it is better to employ gear which pushes the bundle from the rear and is fastened to the shell flange, thus ensuring that all horizontal loads are internal to the exchanger.

The removal and transport of tube bundles can efficiently be done by an "A" frame with lifting chain blocks and mounted on rubber-tyred castors.

The modern tendency to centralize maintenance skilled labour in a central workshop emphasizes the need for ready transport of parts such as tube bundles, electric motors, pumps, and valves over considerable distances. However, the distance is not usually too great for the efficient use of a tractor and small trailer which can be manœuvred into the restricted spaces to collect its load. A trailer can be used in conjunction with the portable lifting frame for motors and pumps mentioned above if it is designed to pass between the "A" frame legs.

Refinery maintenance workshops do not differ materially from other general engineering workshops, and the lifting and handling methods conform to common practice. Overhead travelling cranes, electrically driven, supplemented by swinging wall cranes mounted on the columns, are generally sufficient. Aisles and gangways should be laid out so as to permit of the use of a fork lift truck.

A fork truck can be most useful on maintenance work. Its ability to lift as well as carry renders it able, in many instances, to do jobs which would otherwise require a crane in conjunction with a tractor and trailer or a lorry. Its comparatively small size and high degree of manœuvrability enable it to work in confined spaces. When a Buxton-approved model is available, which can be employed on a unit which is on stream, its usefulness will be greatly extended.

The saving which may be expected from the medium size fork lift truck—say 4000 to 5000 lb capacity—naturally depends on the class of work on which it is employed. On such jobs as dismantling and removal to workshops of electric motors, large valves, and pumps, it has been found equivalent to a gang of eight men, with a considerable saving in wages and overheads apart from increase in speed and convenience.

No other piece of equipment for the maintenance engineer can show such savings in time, labour and trouble, and, with its ancillary equipment, such versatility as the fork lift truck.

The handling of refinery stores, except the tube bundles already referred to, does not present special problems.

While it is convenient for the stores and workshops to be adjacent it is not of vital importance; 70 per cent of all engineering stores go direct to the refinery and the remainder via workshops. By reason of its exclusive employment on maintenance work the flow of material is to and from and not through the workshops. This means that heavy lifting gear in the shop may be concentrated at one point or in one bay, with consequent advantages in building economy.

Miscellaneous Materials

Various materials other than engineer stores have to be handled, and include those normally received in sacks (paper or jute) such as catalysts,

clay (fuller's earth), and bauxite, or received or despatched in drums such as bitumen, lubricating oil, and additives. Slabbed wax in sacks is a special case demanding special consideration.

The fork truck and pallet system of handling and storage is usually the most efficient and least costly for bagged or sacked material. The capital cost of pallets is, however, high, and much depends on the rate of turnover of the stored material. Unless the complete store is turned over at least four times a year the use of pallets must be very closely investigated. On the credit side is the release of labour for more productive work, increased store capacity, quicker turn-round of vehicles, and to some extent a reduction in damage to, for example, paper sacks.

It will be found advantageous to standardize one or two pallet sizes for use throughout the refinery. It is intended to publish in the near future a British Standard for pallets, and the overall sizes chosen should conform to this. It will be convenient if one side of the pallet is 40 inches long for accommodation in road or rail vehicles with minimum space loss.

Unfortunately, sacks and bags vary considerably in overall size, and no one pallet can accommodate perfectly all those likely to be met with, but a good compromise is 60 × 40 inches. This will take six 35-gal bitumen drums (20 inches dia) or four 44-gal lubricating oil drums (24 inches dia over rolling hoops).

Where large quantities of bagged material are regularly received, the throughout palletization from the manufacturer's works by road or rail is worth investigating. The return of empty pallets may be arranged at special rates where the trade is regular. As an alternative the bulk transport of powdered and granular materials is worthy of consideration. Railways and road haulage are now being equipped with suitable bulk water-tight containers.

The cost of bags may amount to as much as £2 10*s* per ton of material. Bulk handling and the use of hoppers or storage bins can also replace stores buildings, pallets, fork trucks, and the handling of individual bags and sacks.

Many powdered materials can satisfactorily be handled by pneumatic means.

Some materials, for example slabbed wax, are incapable of supporting a superimposed load. In such cases post pallets are used, that is, pallets with a post at each corner on which the weight of the upper pallet rests. These pallets are more costly and have the added disadvantage of requiring very accurate placing of the upper pallets, this being reflected in lower handling rates. However, very clear savings can be shown as compared with hand stacking.

The annual cost of a medium size fork truck and 1000 pallets, assuming the capital expenditure to be written off over five years and including maintenance, spares, fuel, and wages with overheads of a driver, is about £2300. To do the same amount of work by hand at least ten men are needed at an annual cost of not less than £7500. Allowance has been made here for the labour necessary for making up pallet loads.

Power-driven stacking machines for sacks, etc., have a place intermediate between hand labour and the fork truck and pallet system. They can be justified in many cases where large quantities of material are not

involved or where turnover is small. They have the advantage of lower capital cost, since pallets are not used, but need to be supplemented by other equipment and labour to move material to and from the stacks.

Oil Tanker Shore Connexions

Most shore connexions are made with flexible hose whether the tanker lies to a jetty or off shore; in either case lifting gear is necessary to get the hose on board. Since this requirement is constant throughout the tanker's life and occurs at every port of call, proper provision for the handling of hoses must be made.

Submarine lines must be got on board, by improvised means if no derricks exist, generally to the detriment of the lines.

For jetty work up to four lines may be connected apart from bunkering, steam, or other services, and it is beyond the capacity of the one or, at the most, two derricks which are available to support them satisfactorily. Flexible hose presents a potential danger from bursts at any time, and the danger is greatly increased when the hose is strained by mishandling and inadequate support.

Cradles are necessary to ensure that the minimum safe radius—about 1 ft for each inch of nominal bore for heavy hose—is not exceeded. They may be made up in pairs and be suspended from a crane or derrick. If the crane is mounted on the jetty it can aid in the handling and making up of hoses into lines. If two lines of 10-inch-bore hose are supported on each crane its capacity cannot be much less than 5 tons, since lines 60 ft long or more may be required for large tankers.

Other and simpler forms of lifting gear may be employed, such as the gantry in the form of a " goal post " standing close to the jetty face, but this does not aid in assembling and making up hose nor in getting the line up to the ship's manifold. Modern practice and the use of large bore high pressure hose with its increased weight demands a more adequate type of gear.

The simplest piece of equipment which can in any way meet all requirements is the hand scotch derrick, which, however, is slow and somewhat obstructive of the jetty deck. The latter objection can be overcome by adopting the post crane, but this requires special jetty design to cater for the imposed horizontal loads.

All-metal lines with swivel joints are being used in the U.S., and have many advantages. The possibility of bursts is eliminated, as is the movement and assembly of flexible hose, and greater development along these lines is anticipated. Lines may form their own arms reaching out to the vessel, with the aid of a simple structure and winch, or may be supported by a crane or the tanker's derricks. Lines are, generally, of steel, but aluminium alloy with swivel joints of the same materials may also be used.

One disadvantage of the all-metal system is the necessary large number of glands with packing requiring maintenance. The most satisfactory arrangement would probably be to combine flexible hose and swivel joints to the best advantage. The present tendency to increase loading rates and pressures will probably eventually limit the use of long lines of flexible hose on account of weight and cost.

Marketing

In marketing installations and depots, material handling consists mainly of the movement of packed products from filling points to road and rail loading points or lighters, etc., for distribution within a market area. In some instances this work includes drum and tin making and the movement of the ancillary raw materials, and the handling of such products as block bitumen, bagged wax, etc.

Handling methods vary considerably, dependent on turnover, and it is difficult to give an overall picture of the equipment used for any given movement.

Small Depots

In the case of small throughputs materials are quite often moved entirely by hand methods as there is insufficient work to justify such equipment as a fork lift truck, which would only be used occasionally. The construction of floors at platform height for direct loading to vehicles could be an advantage.

Empty containers are mainly handled from receipt to filling by hand, roller gravity conveyors being used to speed up throughput at such places as the feed to filling points, and from there to final inspection. Filling, weighing, marking, stencilling and fitting, tightening of bungs, etc., should be done on the run of the conveyor wherever possible.

If bung tightening spanners and spray guns are slung by overhead counterbalance convenient to the operator's hand, throughput is speeded.

Buffer stocks should, if possible, be kept mobile on the roller conveyor up to the point of loading.

For loading into road and rail vehicles, semi-mobile drum loaders are used to pick up at the feed point. Drums can be loaded either on end or on the roll as desired. Where depot stocks have to be maintained, stacking should also be accomplished by this equipment, by means of which stacks up to three drums high on their sides are practical. Usually one operator and one helper are adequate. Dunnage wood is placed between layers with stacking taking place from the end of the stack.

Packed products such as lubricating oil tins in cartons, grease pails, etc., are moved mainly by hand, but the use of gravity roller conveyor, stillages, and hand pallet trucks for long movements has greatly reduced the physical effort and increased throughput.

These same remarks also apply to the greater use now being made of drum hand trucks, drum decanters, etc.

Installations

In large distribution installations much greater use is made of mechanical equipment.

The feeding of tins or drums to filling points is, wherever possible, arranged on gravity or powered conveyors, and all necessary processes are carried out whilst the container is on the conveyor, so that it arrives at the marshalling point ready for delivery or stacking.

With the advent of the fork lift truck the movement of materials has been revolutionized. Small packages can be marshalled into large unit loads such as blocks of several cartons of small lubricating oil tins, fifty or

more 4-gal kerosine tins, small kegs of grease, bagged wax, and similar packages, even up to a capacity of 2000 lb. These are placed on a pallet and thereafter handled by fork lift truck as a single unit, thus saving an enormous amount of handling and physical effort.

The movement of drummed products is probably the major problem in distribution, and it is here that the fork lift truck is most largely used. Normally all drums are handled without pallets, but there are certain exceptions, such as bitumen products or lubricating oils, which will be referred to later, where pallets are used. By means of fork extensions, drums are handled on the roll up to four at a time and stacked on dunnage wood three or four high.

It has been established that when stored on the roll in dunnage wood the normal type of thin gauge steel drum should not be stacked more than four high, or leakage at the seams may occur. Drums are also stacked in pyramid fashion, but this is not recommended if the appearance of a drum has to be considered, as damage such as denting can be caused during stacking and unstacking.

Lubricating oil in 44-gal drums is sometimes stored on dunnage wood, but, with the increasing tendency in the U.K. and in the tropics to store these under cover to protect their exterior decoration, stacking four high is uneconomical in buildings, being wasteful of vertical storage space. For many years drum racks have been considered the best method of under cover storage for such products, but, due to the very large number of grades usually catered for, even racks can be wasteful of space, and in comparison with modern handling by fork lift truck methods can be slow and cumbersome when operated by slow moving platform stackers or hoists.

The palletization of lubricating oil drums in the horizontal position has been an interesting recent development. A horizontal type pallet, carrying two drums side by side, has been evolved, the fork truck being fitted with three-prong forks for this purpose, and practice has shown that drums can now be stacked up to six high without damage or leakage. The pallet is of light steel construction, weighing only 40 lb, and of low cost. The cost per drum stored is less than equivalent racks.

The operator can pick up either the pair of drums on a pallet for stacking, or the drums only, leaving the pallet behind for loading into vehicles.

The operator can deliver drums in the horizontal position or, by manipulating the three-prong forks, upended.

These horizontal drum pallets are, in fact, equivalent to a flexible drum rack, and a great number of different grades can be stacked without loss of space. Three or four grades may be placed in one stack vertically when a fork lift truck is available, and one or two loaded pallets (two or four drums) can be handled at one time, dependent on truck capacity.

Greater use should be made of multiple fork attachments on fork lift trucks for drum handling. The three-prong forks already mentioned take two drums, or four drums if using short dunnage between, and give a good pay load for average installation working and normal capacity trucks. Where large movements have to be made to wharfside for ship stowage, the four- or even five-prong forks should be used, enabling three or four drums or, with dunnage between the layers, six or eight drums to be moved at one time.

Useful special attachments such as side squeeze clamps and drum carriers are available, but all operate with the drum vertical and are not advocated except under special circumstances and for large throughputs. They all tend to slow down operations and require increased stacking space between alternate pairs of drums. Furthermore, a truck so fitted is unable to tackle normal trucking operations with standard forks without changing the attachment and, therefore, loses a great deal of its flexibility—its principal feature. Nevertheless, where one kind of operation is to be undertaken continuously and a truck or trucks with a special attachment can be allocated economically, this may be a satisfactory arrangement.

The question of whether to handle drums horizontally or vertically often arises. Generally speaking they should be kept horizontal, being automatically down-ended at the ends of filling lines if they are not filled horizontally, marshalled on a pair of floor level rails and picked up by multiple forks in ones, twos, threes, or even fours, dependent on the scale of the plant. Thereafter, they can be temporarily stacked on dunnage or pallets or direct to wharf for picking up by crane sling hooks, or conveniently loaded on to trailers.

In any drum handling scheme the use of pallets adds to the cost and, by handling drums horizontally, these can be dispensed with without any loss of efficiency. As already mentioned, in the case of drummed bitumen palletization has definite advantages, enabling five or six containers at a time to be filled hot on the pallet and thereafter handled by the fork lift truck and stacked for cooling. After cooling, they are returned by truck for topping up and finally stacked.

In the case of block bitumen the use of pallets has been found advantageous. The blocks, after hardening, are stacked three or four deep on steel pallets, and by means of pallet racks or post type pallets can be stored economically as regards floor space, all handling being by means of fork lift trucks as unit loads.

Mention must be made here of the increasing use of pallet racks in product or materials stores. This system is economical in space and cost, and is much favoured where a large variety of different shaped packages are encountered. Especially is this the case in special products and lubricating oil stores, where turnover may be small for many products. These racks consist of a simple steel structure forming shelves on which loaded pallets can be slid or placed by the fork lift truck. Simple flat type pallets can be used, and any condition of loading or type of package on the pallet adopted, provided it is stable as an individual load. Thus, at one level can be stored say small grease kegs, at another level drums of special transformer or medicinal oil, at another cartonned goods, and so on. Each pallet can be withdrawn from the rack without interfering with those above or below.

Cargo Handling

The problems of cargo handling over wharves and jetties in the petroleum industry are not very different from those of normal port working, but the emphasis tends to be on such commodities as drums, empty or full, and drum sheet in packs weighing about $\frac{1}{2}$ to 1 ton.

Drums are usually handled six or eight at a time by multiple cask slings, using wharf cranes or ships' gear, and as cargo are comparatively easy to cope with. Loading rates are up to 15 tons per hour per crane.

An alternative to the crane or derrick is a form of loader which delivers a constant stream of drums to the hold. This should increase tonnage rates and improve ship turn-round, but can probably only be justified on a berth wholly devoted to the drum trade, as loaders lack the versatility of cranes and cannot be much used on general cargo. One loader per hatch or up to five per berth would be required.

Oil drums may generally be stowed on the roll, and this makes a satisfactory cargo. Bitumen drums, being lighter in construction, have to stand on end and present a more difficult problem, especially where the ship narrows and at the turn of the bilge.

Wooden dunnage is required, and may amount to 200 tons for a 10,000-ton vessel.

Drum sheet packs should be provided with wooden battens or suitable supports to form stillages. This enables fork trucks to stack and carry on shore and aids considerably the slinging into and out of holds, thereby improving handling rates and reducing damage to sheets.

The use of pallets is restricted by the difficulty and cost of their return. Goods stored on pallets may, if the pallet is of the wing type, be lowered into the hold without transfer to a cargo tray and the pallet returned to the jetty when empty.

Justification

The cost of installing and operating handling equipment, which is often considerable, is only justified if it shows a profit. This may be in the form of increased output, reduction in damage to goods, reduction of turn-round time with its effect on demurrage, or improved working conditions.

Wherever the movement of materials is regular and frequent, man is the most expensive and inefficient machine for the job. The annual cost of labour for lifting and shifting is far greater than that of any machine. The overheads attached to labour are considerable; they include special pay such as "height" money and "dirty" money, protective clothing, canteens, and frequently travel facilities as well as holidays with pay. Labour demands supervision and general administration such as PAYE and time checking. The cost of equipment, apart from amortization, includes costs of fuel and maintenance, and is about proportional to the work done. Idle labour costs as much as employed labour, but efficient handling schemes ensure that labour is effectively employed in productive work.

One aspect of this problem which is becoming increasingly apparent is that cheap local labour overseas is no longer readily available. With the increasing demands for housing and other amenities, the cost of local labour is approaching and, in many cases, exceeding the cost of labour in the U.K.

The provision of handling equipment is, therefore, as important in overseas installations as in the U.K., but with the added difficulty of training unskilled labour in its proper use and maintenance.

In deciding whether the installation of handling equipment is justified, a comparison must be made with other methods such as hand labour or

hand labour plus partial aids. This is best done by comparing annual costs. The annual cost of equipment may often be shown to be unnaturally high, due to a company policy of writing off capital expenditure in a fixed short period regardless of its actual life. Even if the period is as short as three years it can usually be shown that mechanization is cheaper than labour.

The annual cost, including overheads, of one labourer equals the cost of £1750 worth of equipment paid off over three years, including maintenance and other charges. Therefore the use of a fork truck costing £1750 (making due allowance for the driver) can be justified wherever it replaces more than two men. Since it can do the work of a gang of at least eight men, the potential saving is very clear. If a write-off period of five years is adopted £2500 worth of equipment may similarly be justified.

General Principles

Mechanical handling is not an end in itself. One object of any layout of factory, store, or refinery must be to reduce movement and, therefore, handling to a minimum. All movement is a costly necessity.

From an analysis of cost it is fair to say that on an average, handling represents between 50 and 75 per cent of the finished cost of packed products. An example of what economies in handling can do is shown by recent improved methods introduced at a large lubricating oil distribution depot in the U.K.—by the use of fork lift truck methods turnover increased 100 per cent with no increase in labour force. By the employment of women as truck drivers some economy has been shown in overall labour cost.

Again, certain railway parcels departments, in the U.K. and on the Continent, have greatly benefited by better handling methods, *i.e.*, fork lift trucks, conveyors, pallets, containers, etc., and to cite one case in the U.K. the handling time per ton has been reduced from 2·6 to 1·6 man hours and labour released for other work. It is obvious that economies in the field of handling can pay very large dividends.

What must be done to improve handling methods? First, the principles to be aimed at to get maximum efficiency must be considered and examined to see how far this has been achieved or what further improvement can be made.

It must not be forgotten that the perfect material handling scheme would be one in which there would be no man-handling.

Flow of work is probably the most important point to be studied, and this involves the correct siting of reception points for stores and process material and of filling areas for products in relation to the loading points. Distances between points must be minimized and, in the layout of a plant or refinery, the proposed handling system must be given early consideration. To obtain maximum economy, the layout must be based upon the basic principles of materials handling, the best use of the most economical equipment available, and its application in the right place.

The main principles to be aimed at are :—

(1) *Direct Flow.*—Routing of stores and products must be carefully studied; bottlenecks must be avoided if possible. Wherever feasible,

receiving stores and filling of products must be in tune with requirements of plant and customers' orders, so as to cut down intermediate storage and unnecessary double handling.

(2) *Storage Areas.*—Where temporary storage is necessary, this must have easy access to the direct flow and be convenient to loading points.

(3) *Unit Loads.*—The unit load, which is an important point today, must be devised in terms of package and handling equipment. Products must be moved in the largest possible units within the capacity of the equipment, either as individual units such as 44-gal drums unpalletized or palletized, or as palletized unit loads of such commodities as cartonned lubricating oils, greases, and chemical products, bagged wax and clay, etc., to the extent that special pallets may be necessary to accommodate empty 4-gal tins and similar crushable packages in order to accomplish high stacking.

(4) It is easier to move an empty package than a full one, and the re-positioning of discharge points or the re-arranging of a plant can often reduce the necessary movements of a full package.

(5) *Balance Working.*—Whatever handling equipment is adopted, whether it is an overhead cable way, tractor–trailer system, or gravity roller conveyor, every link in the chain must be synchronized so that each is employed at the same working speed.

(6) The handling problem starts at the factory of the material supplier and, to achieve efficiency, the most economic form of package to fit into the reception scheme must be agreed with the supplier. The problem continues until the product reaches the customer.

(7) *Surfacing.*—Although the importance of good access roads and paved areas is now appreciated, there is still much that could be done in this respect. Good, even surfaces mean reduced maintenance costs for equipment and speedier turnrounds. The surface should be sufficiently hard and consolidated to withstand the wheel loading of the equipment, and this can often be achieved by using hard-core with a suitable dressing, without resort to expensive concrete finishes.

(8) *Buildings.*—Single storey buildings are, except in unusual circumstances, the best for storage sheds, a height to eaves of 16 ft approximately being ideal. This allows for stacking four drums on end on pallets or six drums high on their sides with pallets, if necessary, with ample working clearance.

Buildings should be designed with a minimum of internal framing such as roof trusses, knee braces, etc., to interfere with stacking arrangements and movement of mobile equipment, such as fork lift trucks, or stacking arrangements such as pallet racks.

Double span buildings with valley columns should be avoided if possible. The ideal would be two- or three-pin rigid frame construction free of all internal obstructions, thus permitting stacking up to the underside of roof sheets if desired.

The necessity of raising store sheds to platform height for ease of loading can, in many cases, be dispensed with by the use of fork lift trucks, drum loaders, and other similar equipment. Orders can be marshalled at ground level and then loaded direct to vehicle with the equipment available.

Daylighting of storage buildings should also be given serious thought. With the high stacking and narrow gangways possible to-day, good, evenly dispersed lighting is essential over the whole floor area with sufficient intensity to aid stacking and rapid identification of stocks. Large numbers of small roof lights evenly dispersed over the roof slopes and using diffusing glass are preferred to the normal strip glazing and side lighting. It has been found that dispersed lighting is far more efficient and provides shadowless lighting even in the deep centre gangways of large stacks of palletized loads or drum stocks.

Types of Equipment

Gravity Roller Conveyor

This is probably the most common and the oldest material handling equipment met with and, in its various forms, has a variety of uses. Wherever material has to be moved over short and direct routes some form of conveyor can generally be used. Where elevations are such that advantages can be taken of gravity, then the gravity roller conveyor can be used. It is manufactured in convenient standards to suit different weights, shapes, and sizes of packages, and can be made of tapered rollers to follow a circuitous route if necessary. Standard portable sections of conveyor are available in lengths of 8, 10, or 12 ft either flat or mounted on adjustable legs. Increased use could be made of this equipment for loading between stock piles and vehicles and similar movements.

There are many instances where, by installing short lengths of roller conveyor, much physical effort can be saved and throughput speeded up. Particularly is this so in filling arrangements for large packages such as sacks and drums; often drums are delivered to a weighing machine by roller conveyor and then laboriously skidded on and off the weighing platform, this sometimes involving a lift of several inches. By having the weighing platform in the run of the conveyor a continuous flow could be achieved with the minimum of physical effort. Of the packages most commonly used the following types of gravity conveyor are recommended :

Gravity Roller Conveyor
Free roller type—Ball-bearing mounted

Package	Slope, per cent	Rollers
Empty 4-gal tins, cartons, and similar small containers, wt 2–10 lb	6–8	Light type, 1¼ inches dia, 16G, 2-inch centres for tins, 4–6-inch centres for cartons
Full 4-gal tins, cartons, wt 15–50 lb	3–4	—
Empty drums, wt 50–90 lb	2–3	Medium type 2¼ inches dia, 16G, 3–4 inch centres
Full drums, wt 400–500 lb	1½–2	Double rollers, heavy type, 3 inches, dia 12G, 4–6-inch centres

Gradients at curved sections increased by 100 per cent

Belt or Slat and Driven Roller Conveyor

These serve the same purposes as gravity conveyors, *i.e.*, for moving goods from point to point on a fixed route, but are power driven and independent of gravity.

A combination of belt and gravity conveyor is sometimes the most economical method of moving packages, but the problem always exists of

getting the packages off and on; this is all too frequently done by hand. There are now many automatic devices for such operations, and manufacturers should be consulted on these problems. Ball top skid plates or tables, automatic ploughs, chutes, turntables, switches, etc., suitably employed all add to the overall efficiency of a conveyor system and release manpower. Care should be taken that all feed and discharge points are correctly levelled to minimize physical effort when packages have to be manhandled on to a conveyor system.

Elevators

These are usually employed in a fixed conveyor system for overcoming large differences in working levels, such as in multi-storey buildings or where insufficient space is available for long inclined slat or belt conveyors.

Overhead Chain Type Conveyors

There are many types of this conveyor available which are most useful in drum and tin factories and, in particular, painting and reconditioning plants. It occupies no floor space, and can be run at any height and, due to its flexibility, can be snaked up or down to clear obstacles. Various types of hangers are available or easily designed to suit different packages and process movement, including rotating hooks for use in painting booths and cam operated short lift hooks for loading and offloading heavy containers such as propane bottles, etc.

Tin Factories

Mention can conveniently be made here of the assistance gained by use of gravity chutes at feed or discharge points to such machines as tin presses, etc. The fitting of small belt or light rope conveyors between machines, the introduction of mechanical fingers where applicable on presses, and other simple aids have their value in the overall picture.

Aerial Ropeways

Consideration must be given to the use of aerial ropeways where distances are great and the package is suitable; very often this method of transportation can be economical. It has many advantages, and in such instances as the feeding of dockside areas where a constant stream of, say, drummed products from a distant filling or storage point is necessary, it may well be a better answer than tractor and trailer systems or a narrow gauge railway. Very often is this the case when feeding along existing jetties; ground level movement may involve considerable rebuilding programmes to give adequate traffic way, which can be avoided by adopting overhead movement.

An aerial ropeway can take the shortest route between terminals and is, therefore, often independent of installation or refinery layout, and large variations in levels can be easily overcome. It will frequently be found to be the answer to a problem in congested areas.

Fork Lift Trucks and Pallet Trucks

The fork lift truck is very compactly designed of minimum dimensions, extremely manœuvrable, being able to turn within a small circle and to

operate in narrow gangways and confined spaces. These features result from a study of stacking problems in the past, and wherever there is a stacking problem a fork lift truck must be considered. This is a power operated vehicle, designed to lift loads on its two or more forks and, by means of a hydraulically operated telescopic mast, lift the load to heights up to 12 or even 16 ft. Various attachments, other than forks, can be fitted to the lift carriage. These include crane jib, swivel head, side bale clamps, drum or bottle carriers, etc., all of which add greatly to the versatility and general usefulness of the machine around a refinery or installation.

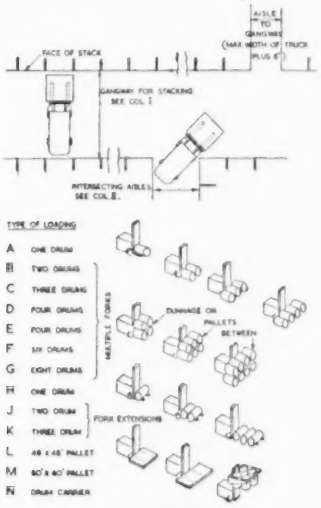


FIG 1

As already mentioned, there are numerous cases where this equipment must be considered, but, as there are many different types and sizes of truck, it is necessary to decide on suitable types for our industry.

Capacity.—Taking truck capacity first, there are three sizes that should be considered. For general all round working the 4000-lb capacity truck with a 12-ft lift is best for most operations, and especially where continuous working with a full capacity load can be achieved, as this enables a load of up to eight 44-gal drums or 100 4-gal tins to be handled. In special cases, however, such as handling liquid gas bottles or where the use of a carrier attachment is advantageous, a capacity of 5000 or even 6000 lb may be necessary to overcome the deadweight of the attachment and leave a suitable margin for the maximum unit load. In these cases also an increased lift of 14 or 16 ft may have to be considered. There is a good case also for a smaller truck in depots or for specialized movements in a larger material handling scheme, such as the 2000-lb vehicle having a 9-ft lift.

Fig 1 gives diagrammatically the more usual type of loading, and Table I

lists dimensions for gangway and aisles, etc., for the types of truck referred to. Table II gives product tons handled per hour for various unit loads.

TABLE I

Table of Dimensions for Typical Diesel F.L. Trucks

Dimensions in inches

Loading		Types of trucks			
		Coventry climax		Stacatruc 2 DH, 12-ft lift 4500 lb	Conveyancer D6 20, 12-ft lift 6000 lb
		TMD, 9-ft lift 2000 lb	FTF, 12-ft lift 4000–5000 lb		
Column I: Gangways	A	118	145	143	148
	B & E	118	145	143	148
	C & F	121	148	146	151
	D & G	—	150	148	153
	H	106	145	143	136
	J	130	157	155	160
	K	—	181	179	184
	L	130	157	155	160
	M	123	150	147	152
	N	—	162	160	168
Column II: Intersecting aisles	A	62	86	84	88
	B & E	70	86	88	88
	C & F	82	97	100	99
	D & G	—	109	112	111
	H	64	86	84	88
	J	64	86	84	88
	K	—	86	84	88
	L	70	86	88	88
	M	76	91	94	93
	N	—	86	88	88

TABLE II

Drum Handling

Based on a cycle of operations of 2½ min

Unit load	Product, tons per hour	
	36-gal drums 6·4 drums/ton	44-gal drums, 5·6 drums/ton
1 drum	3·7	4·3
2 drums	7·5	8·6
3 drums	11·2	12·9
4 drums	15·0	17·0
6 drums	22·5	25·7
8 drums	30·0	34·0

Motive Power.—Fork lift trucks are available with electric, petrol, or diesel drive, and each has its particular uses, but for general all round conditions almost exclusively in the open or well-ventilated areas, the diesel driven models are most suitable. The operation of these trucks in dangerous areas must be considered, and this rules out the electric vehicle.

To make it flameproof is expensive, and battery charging and maintenance can present certain difficulties.

The preference lies with diesel drive as, basically, the diesel engine is safer, easier to flameproof, and lower on running costs than the petrol engine. All electrics can be dispensed with, and starting may be by hand or compressed air, with flame-traps on the air intake and exhaust. In areas where low flash products are handled, trucks having a water-washed exhaust system have been used as an extra precaution in certain cases, although present models do not carry a Buxton certificate. The use of pneumatic or cushion tyres is recommended in preference to solids, largely from the point of view of reduced maintenance work and better riding conditions for operators. All trucks should be fitted with overhead load guards and canopies if for use in tropical areas.

Attachments.—There are many attachments and other devices available to increase efficiency and versatility, enabling trucks to be used in a variety of ways. However, the more specialized attachments, such as drum carriers, side clamps, etc., should be used with discretion, as referred to previously. Fork extensions and multiple forks can be supplied to requirements, and should be used as standard equipment. Jib or crane attachments are also useful for lifting loads out of vehicles, and for general maintenance work.

Training of Operators.—Without efficient truck operation the great potential advantages of this equipment can be lost. It is, therefore, necessary to see that fork truck operators are properly trained not only in stacking, loading, and unloading operations, but also in the proper handling of the equipment to reduce maintenance and to reduce accident hazards to both personnel and packages.

Light Railways and Tractor–Trailer Systems, etc.

A fork lift truck should be mainly employed in loading and stacking. It is much heavier in relation to its pay load than is a lorry or tractor and trailer, since the load is located outside the wheel base and must be counterbalanced. For this reason, and because much of the cost of the truck is invested in the lifting gear, travel should be minimized. A distance of 300 ft is generally regarded as about the economical maximum, additional travel increasing wear and tear unnecessarily.

For long hauls, therefore, alternative equipment must be sought. For distances up to about 1500 ft, tractors hauling a train of trailers must first be considered. Where fork trucks are available an efficient material movement can be achieved by use of a combination of both systems, using fork trucks to load and unload at either or both ends, dependent on the scale of the whole scheme. Where pallets are employed the entire operation can be greatly speeded up, the loaded pallets being transported on the trailers to the unloading point and returned empty on the reverse journey. Alternatively, these can possibly be reloaded with incoming products, with a consequent saving.

Maximum economy in handling materials is obtained by reducing standing or idle time. Therefore, the tractor should be disconnected from its train of trailers at each end of its haul, for, like a locomotive, it is designed to haul load-carrying units and not to wait at terminals. It should be

released quickly at terminal points, so that it can spend most of its time performing duties for which it is designed.

Above distances of 1500 ft, especially if public roads have to be considered, motor trucks are generally more economical than a tractor–trailer system. They are faster, particularly over rough roads, thus getting a quicker turn-round. Here again, there is further economy if palletized materials can be carried in transit, especially if fork trucks are available at both ends for loading.

Mention must be made of the mechanical horse and trailer system. These carry up to 3 tons per trip at 20 to 30 m.p.h., are suitable for public road transit, and have the added advantage that spare trailer units can be loaded and unloaded while a loaded trailer is in transit hauled by the mechanical horse. This is a similar arrangement to the tractor system, transporting less loads per journey, however, but at a high speed, and suitable for distances of several miles.

The type of trailers used should be of robust construction, preferably pneumatic or cushion tyred, with roller or ball bearings. They should have Ackerman type steering with removable towing links to make them easily reversible. This is important where narrow jetties or gangways are to be negotiated, in order that the tractor can be disconnected from the front and connected up at the back of the train for hauling in the reverse direction, without turning the whole train round. This trailer tracks exceedingly well, and the whole train can be reversed in a 16- to 18-ft corridor.

Diesel trucks are available, as standard trucks or fully flameproofed, for hauling loads up to 15 tons.

Larger tractors, diesel driven, capable of hauling loads up to 100 tons, are supplied where shunting operations also have to be undertaken. These are not yet obtainable fully flameproofed.

When large quantities of drums, tins, etc., have to be moved long distances, say from storage sheds to jetty, then these methods must be considered. Up to the present time much of this work has been catered for by the light gauge railway or decauville track and its sets of wagons, either pushed by hand or hauled by a small locomotive. The disadvantage of this system is its limitation to a fixed track or route, with a consequent lack of flexibility. Therefore, it is being largely superseded by the alternative methods already described.

Education

One of the most important contributions of mechanical handling, apart from the obvious benefits of increased productivity, is the improvement in working conditions. When lifting and shifting have been handed over to machines, men may turn to more interesting and profitable work. The implication is, however, that a higher degree of training and ability are called for, and both time and money must be spent to achieve it.

It is not to the benefit of the community that a large portion of its industrial manpower should be non-productive, *i.e.*, misused. Every man released by mechanization to become a producer benefits the community as well as the individual.

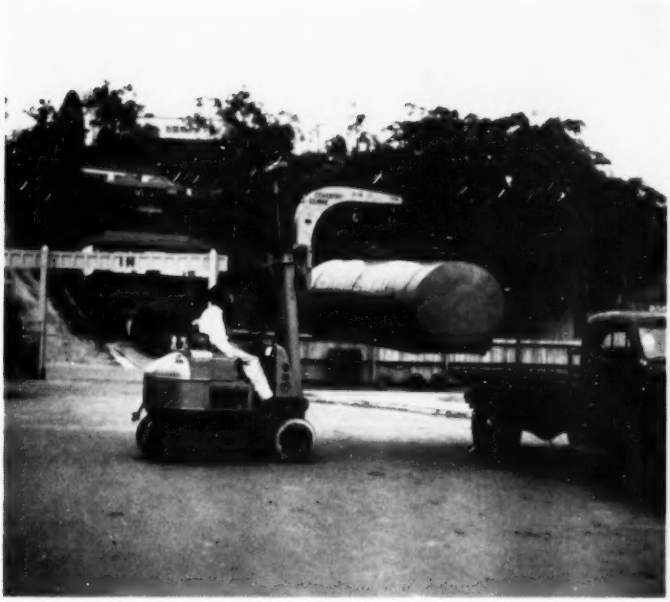


FIG 2

FORK LIFT TRUCK WITH CRANE ATTACHMENT

FIG 3

LOADING RAILWAY WAGONS

[To face p. 812.

Fig. 4
DANGEROUS AND . . .

Fig. 5
. . . ARDUOUS CONDITIONS
OF WORK. . . .

Fig. 6
. . . OBVIATED BY MEANS OF A
SIMPLE HANDLING APPLIANCE

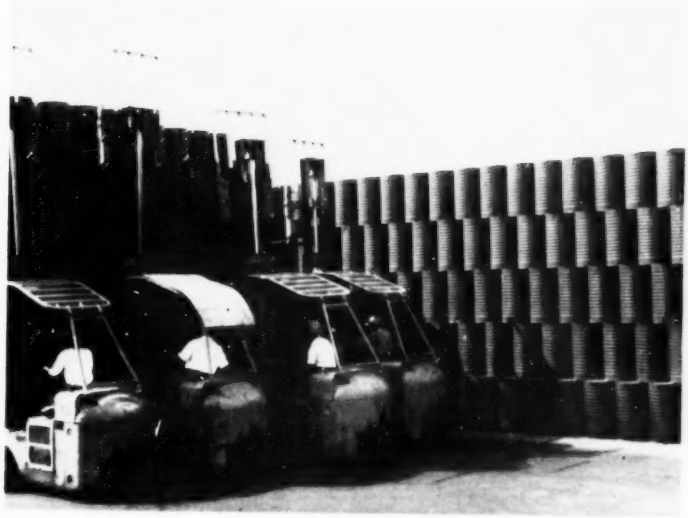


FIG. 7

WHERE THE FORK LIFT TRUCK IS NARROWER THAN THE LOAD, ANY NUMBER MAY WORK SIDE BY SIDE. . . .

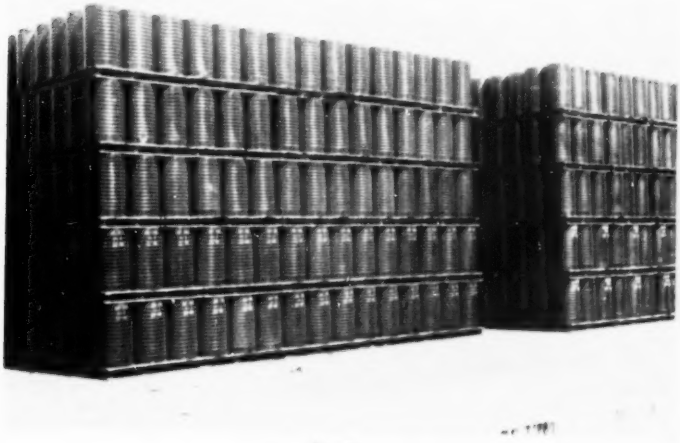


FIG. 8

. . . AND PRODUCE NEAT STACKS OCCUPYING A MINIMUM OF SPACE

FIG 9

FOUR DRUMS ON TWO PALLETS LIFTED ON NORMAL FORKS

FIG 10

HORIZONTAL STACKING FOR DRUMS STRONG ENOUGH TO SUPPORT A SUPERIMPOSED LOAD ON THE ROLL

It is generally possible by argument and demonstration to convince management of the advantages of such equipment. It is more difficult, however, to persuade labour, as the first effect of the system appears to be in the interest of management only; moreover, the arguments in favour of the change, coming as they do from management, may be suspect. Fortunately, however, in the petroleum industry the possibility of redundancy is likely to be offset by the anticipated expansion in output, thus removing the main objection by labour to the projected equipment.

There is little doubt that labour quickly appreciates an improvement in working conditions, and that the objection to mechanization centres largely round the possible loss of employment.

Discussions between management and labour, together with courses of instruction and films for both operating staff and labour, are desirable as an aid to better understanding by both sides of the advantages to be gained by use of this equipment.

Future Developments

Serious consideration is being given by shipping organizations and others to improved methods of stowage, particularly from the aspect of increased rates of loading and unloading. The regular size of most parcels in the industry is a help towards this end. Pallet and fork lift trucks are used in ships' holds with advantage in many cases, and are particularly useful in striking cargo from the wings. Many difficulties have to be overcome, for example in accommodating the heavy wheel loading inherent in fork lift trucks, but it seems likely that the advantages to be gained justify some modification to the design of ships.

An interesting possible future development is the use of the straddle truck, a vehicle mainly used in the timber trade. As the name implies it is designed to straddle the load, which may be a stack of timber, pipes, or loaded pallets, and is designed to transport loads up to 20 tons weight. It is envisaged that loads of, say, eighty 44-gal drums can be picked up and moved over ordinary roadways at 30 m.p.h.

In a constant search for ways of reducing costs there is no single factor which can contribute more than the adoption of efficient handling methods. In particular, there must be an improvement in refinery layout and plant design to ensure good access to all areas where maintenance has to be carried out, and the provision of adequate gear to handle the loads. The areas surrounding units must be capable of supporting mobile cranes, heavy fork lift trucks, and trailers. Packages and containers may with advantage be modified in shape so as to be capable of assembly in regular parcel units. Greater use should be made of fork lift trucks and, where necessary, pallets. It is most desirable to handle chemicals in bulk, whether by road or rail, and to avoid the handling of individual small quantities.

Developments in equipment which would prove valuable should include the Buxton flameproofing of fork lift trucks and tractors, and the wider use of cushion type tyres which combine to a large extent the advantages of the solid and pneumatic types. It would also appear that the provision of a fork lift truck lifting 3000 lb is desirable. This would fit in with both maintenance and distribution requirements in the most economical way.

An improvement is also clearly called for in the facilities on jetties for connecting tankers to the shore. There are economies to be gained by the elimination of flexible hose and a great improvement in safety conditions. Solid pipe and swivel joints are already in use as a satisfactory substitute in the U.S.

Finally, there is a case in large installations for the provision of radio control, especially on maintenance and construction, where the work is not routine. It is possible by this means to ensure that the maximum use is obtained from mobile cranes, fork trucks, lorries, and similar equipment.

Discussion

The Chairman : One of the disadvantages in mechanical handling with fork lift trucks is the expense of pallets, hard standings, concreting yards, and so on.

In connexion with flameproof equipment, the IP Engineering Committee are considering where non-flameproof equipment can be used. In many areas outside buildings, or inside well-ventilated buildings, one need not go the whole way towards flameproofing equipment. The water wash exhaust is a piece of equipment one would like to get rid of, and its dismantling and cleaning is a laborious and expensive job.

I have pleasure in asking Mr Driscoll to open the discussion.

W. H. Driscoll : I am sure that all refineries are interested in mechanical handling as a means of reducing the need for man-power, since not only is the financial gain a strong incentive, but, due to the relatively remote location of the average refinery, labour is scarce, and can be hired only with difficulty.

The most important aspect of mechanical handling to a refinery is its valuable use on major turn-rounds, and one must use every device to reduce down-time to the absolute minimum. Palletization of equipment on removal from a unit and during subsequent mechanical handling through the shops and back to the unit saves much time during annual overhauls. Valves, pumps, motors, heat-exchanger bundles, shelves, etc, are picked up, placed on pallets, and then removed by straddle truck to the workshops, which, depending on the particular unit shut down, are up to $\frac{1}{2}$ mile distant.

Further aids to fast handling on turn-rounds which have been developed might be of interest. Chutes made out of scrap pipe are installed from platforms down to ground level. By means of these, rubbish, such as catalyst, insulation, oil spills, etc, which would otherwise make for poor working conditions, is quickly accumulated into drums, already mounted on pallets waiting below.

A second aid to speedy handling up and down towers and drums is our practice of installing a built-in davit over every tall vessel. During pre-turn-round preparations, a snatch block is rigged to it, operating in conjunction with a portable air winch and cradle. By this means, caps, tray sections, and valves can be raised quickly up to any desired manhead.

A small, but very efficient, time-saving aid is to install built-in davits on hinges on all heavy manhead doors. Extra-large manheads encountered

on cat units are provided with permanent overhead gantry rails, whereby such doors can be swung out and stored vertically in prepared cradles for the duration of the turn-round. The big slide-valves on the cat unit weighing up to 9 tons each, are also equipped with overhead gantry rails, making their removal from the structure and re-location a relatively easy matter.

We heartily endorse the authors' statement that, for efficient maintenance, good access, heavy-duty roads, and built-in handling facilities are necessities.

Our experience of fork lift trucks is very good, although they are employed exclusively in our stores, loading, unloading, and stacking all materials from hardware to chemicals.

Of prime use on our refinery are machines mentioned earlier—Ross Carriers. These are a development of the straddle truck mentioned in the section of the paper devoted to future development. The machines can straddle a palletized load of up to 13 tons, 5 ft wide and 5 ft high, and the speed of the vehicles is around 25 miles per hour, maximum. These carriers are invaluable, and they are used for carrying all materials, including the largest 900-tube heat-exchanger bundles, weighing up to 9 tons, and also drums, timber, chemicals, pumps, motors, etc.

Another good aid in reducing hand labour is the tailboard loader truck. It consists essentially of a regular 5-ton lorry with a specially fitted tailboard. The hydraulically operated lift can handle up to 3 cwt, lifting equipment from ground level up to bed level, from where it can be slid or rolled onto the bed of the truck.

Another piece of equipment is the Krane Kar. This is essentially a small compact crane, capable of hoisting loads up to 7½ tons to a height of 12 ft. Its compact design (wheelbase 101 inches, overall length 134 inches, and width 74 inches) makes it invaluable for a job such as moving along a line of pumps during unit turn-round and transferring both motors and pumps onto pallets, ready for fast removal to shops by Ross Carrier. Its one disadvantage, however, is the high wheel-loading of up to 31,000 lb spread over three wheels. This loading precludes its use on any but the hardest ground.

I would like to enlarge on the authors' remarks on the radio control of vehicles. At Fawley there are ten vehicles fitted with two-way radios, and they are used by key personnel, engineers and craft general foremen. Communication is with a master station at the Transport Despatcher's Office, not between vehicles. The radio units are powered by the 12-volt battery of the vehicle. With such equipment, key personnel can be contacted immediately in an emergency.

The possibilities of conveyor-loading chemicals into towers and drums are being considered. Considerable labour is employed in emptying and refilling drums with clay, salt, catalysts, etc, and the methods used at the moment are most inefficient. It is believed that the use of a mobile conveyor belt, driven by flameproof motor, will pay big dividends. The equipment we contemplate obtaining is a 27-inch wide by 50-ft long portable conveyor, having an adjustable discharge height of between 12 and 25 feet, and a speed of a 100 ft/minute. Any experience of this type of equipment by other refineries would be most welcome.

The authors' remarks on methods of hose handling at jetties and possible

new developments were interesting, and a short description of our own installation may be of interest.

We have a large marine terminal of four berths, each capable of berthing a 39,000-ton tanker. On each berthing point there is a rectangular structure, 53 ft high by 20 ft deep by 60 ft wide on the seaward side. On ground level is the black oil manifold, and at elevation 12 ft, the white oil manifold. At elevation 35 ft are two gantry rails, positioned parallel to the tanker, one flush with the front of the structure, and the other cantilevered 10 ft out from the face. On each of the trolley beams are mounted approximately nine 1-ton high-speed, chain-operated hoists. At elevation 61 ft are mounted five jib booms 26 ft long, extending seawards over the tanker. Mounted on each of these booms are two 1-ton air-operated hoists, controlled from ground level. Flexible rubber hoses, varying from 6 to 10 inches in diameter, and 50 ft long, are handled in easy curves by means of these hoists, each hoist being supported at four points, the outer half being handled by the hoists on the jib booms, and the inner half by the hand-operated hoists on the gantry rails. By means of these hoists, up to five hoses can be connected to a tanker by a crew of four men with relative ease. Allowance is made for the rise and fall of the tide by the hose-handling crew.

We have a big field in front of us in persuading manufacturers to palletize more of their products, as is currently done in the U.S.A. There are also advances to be made in the mechanical handling of chemicals in bulk, instead of packages, and in the mechanical handling in L.P.G. bottling plants.

T. R. Thompson : Could the authors give more details of the type of ram or jack used for pushing tube bundles out of their shells ? It has been said that, in place of fitting chain blocks to pull the bundle out, some gear has been designed to push it out.

Can the authors give an opinion on the relative merits of a battery-operated fork lift truck as opposed to the commonly used petrol-driven vehicle ?

Mr Samson : The ram used to push out bundles from their shells consists of a bridge piece, which is placed across the rear flange of the shell and supported clear of the flange of the shell by short columns. Mounted on the bridge piece is a centre-hole jack which permits a rod to pass through the middle, the rod being fastened to the ram by a cross-member through the rod. When the jack is moved out to its full travel, it pushes on the rod, which in turn pushes on the back of the bundle. In order to spread the load over the bundle, some sort of packing is necessary to reduce the load on individual tubes. This equipment was first developed in the U.S.A., but our own company has developed something much cheaper—it remains to be seen whether it is as satisfactory. It uses either two chain blocks, or two of the well known Pul-lifts, instead of the centre-hole jack. There are disadvantages in the latter, in that it requires a large number of seals, and manufacturers are not in favour of it, but, nevertheless, it is available in that form. The advantages of a bundle pusher are that there is no external load on the shell and on the structure carrying the heat exchanger.

In these days the shells of heat exchangers tend to be much thinner, and there is danger if the load is applied from outside the heat exchanger, of damaging or twisting the shell by applying the full load to the shell feet.

MR REYNOLDS : Regarding the question of electric versus petrol or diesel trucks, for general, all-round operation on a petroleum installation or refinery, the diesel truck is probably the better machine, especially where you get peak loading, or say, breakdowns in a refinery, or going off-stream, or similar urgent operations. The gasoline, or preferably diesel, truck is capable of being worked, if necessary, 24 hours a day at full capacity, whereas electric trucks, under similar circumstances, have to come out of operation every seven or eight hours for recharging.

The second point in favour of diesel trucks is that one can flameproof almost 100 per cent of a diesel truck relatively cheaply, whereas it is almost impossible to do this with an electric truck. But electric trucks have their particular uses, especially where fumes are objectionable, and for working inside godowns or store buildings.

W. E. PHIPPS : We should like to get rid of the water wash exhaust, but cannot find any other solution to the problem. I would welcome any findings from the Institute on this question.

MR REYNOLDS : The flameproofing of fork lift trucks is a costly business, and something to be rid of. I think the best course is to remove or restrict the danger, by keeping all filling operations of dangerous products under such conditions that one can operate a truck which is not fully flameproof. If it is necessary to take drums that have been filled, say, with gasoline, out of a dangerous area, surely the simplest thing is to remove them from the filling points on conveyors, and pick them up in a safe area with a non-flameproof truck.

W. M. HURRELL : I should like to ask the authors what their experience has been on pallets for handling bitumen drums. I believe there has been trouble with the warping of pallets. It is rather an expensive form of handling, but there may be no alternative to it.

MR SAMSON : At Abadan we had 30,000 steel pallets, measuring 60 by 40 inches and about 6½ inches deep overall, and we had very little trouble as to any kind of warping. The only damage of any consequence was due to the drivers approaching the stack and allowing the forks to strike the ends of the vertical, central bearer members. That has been overcome, in future designs, by placing a flat plate at the ends of the bearers. We have used wooden pallets only for handling bagged material, and it is unlikely that wooden pallets would be employed, at any rate without steel tops, for handling drums, because of the chimes cutting into the tops. There is little likelihood of any serious damage to steel pallets which are properly designed and used.

THE CHAIRMAN : One point about mechanical handling is that equipment has to be planned extremely carefully to make full use of a limited number

of men. The way the problem is approached on some of our smaller depots and installations is to work out the minimum gang required to do the major job of work, and one then mechanizes to get that minimum gang to do all the work. The equipment is such that all the big drums are filled in the morning, and all the small packages in the afternoon. The actual filling equipment can do twice the throughput required if it was used all day, but one uses that equipment half the day, and gets a small gang of men to do all the jobs. In the U.S.A., that is the main approach to the problem, and there a man works a fork lift truck one moment, and then he will go and dip a tank or do something else. But the tendency is to get too specialized in this country; one must have very versatile labour.

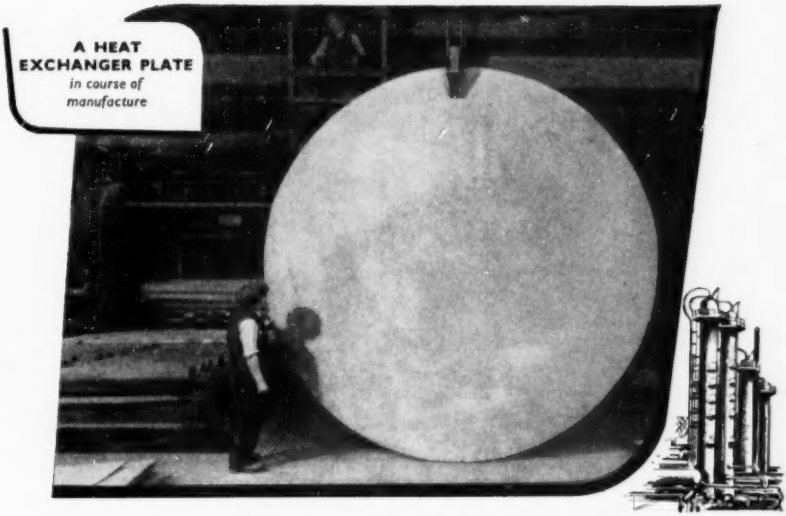
The paragraph on education in the paper is most important. The point to be emphasized when introducing mechanical handling is that it really helps the labourer to live longer; he is not breaking his back the whole time, but getting his job done with the minimum effort.

There is a great deal of attention being given to a subject called " Work Study " at the present moment which comprises method study, work measurement, and incentives, and I think that it all ties up with this mechanical handling problem.

I think we would like to see some of the attachments to fork lift trucks developed in this country: to a great extent, these do away with palletization.

In conclusion, I would like to thank the authors on behalf of all of you, for their very interesting lecture and the very capable way they have answered all the questions which have been put to them.

(The vote of thanks was heartily accorded.)



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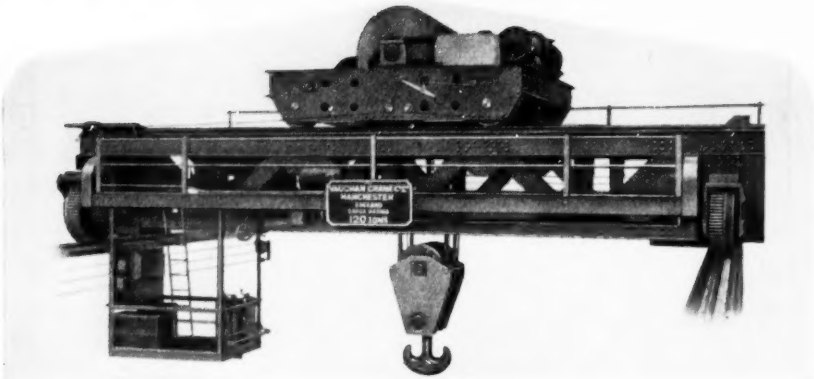

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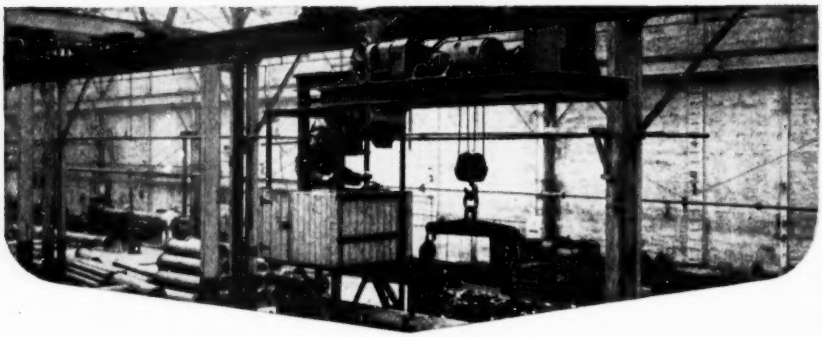

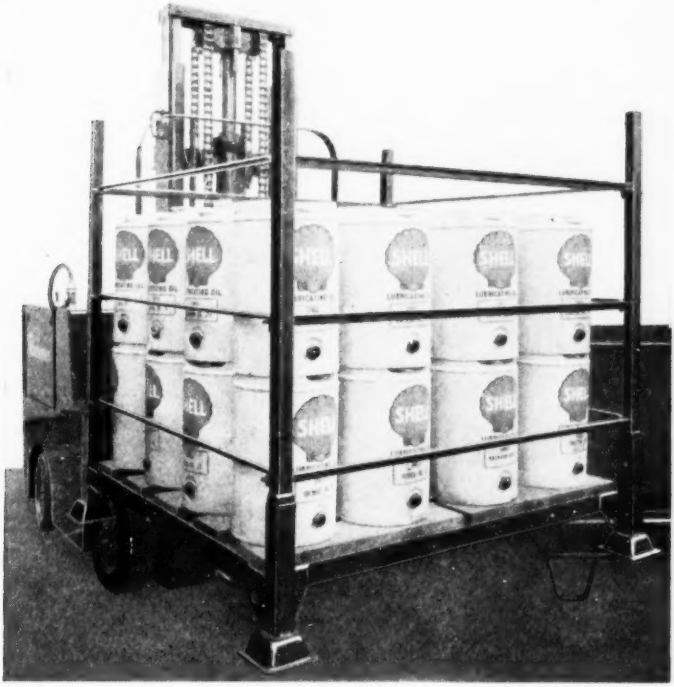

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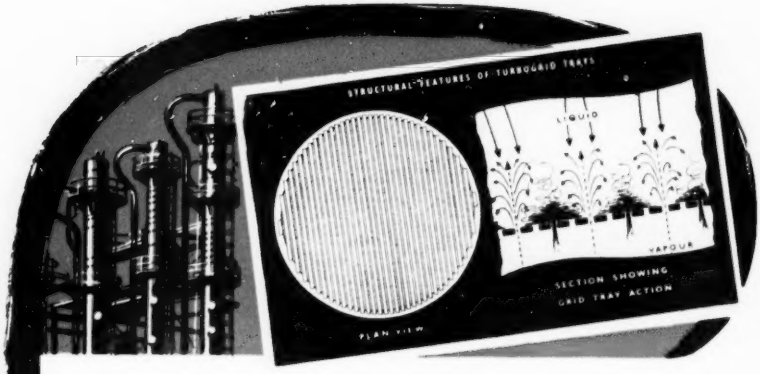

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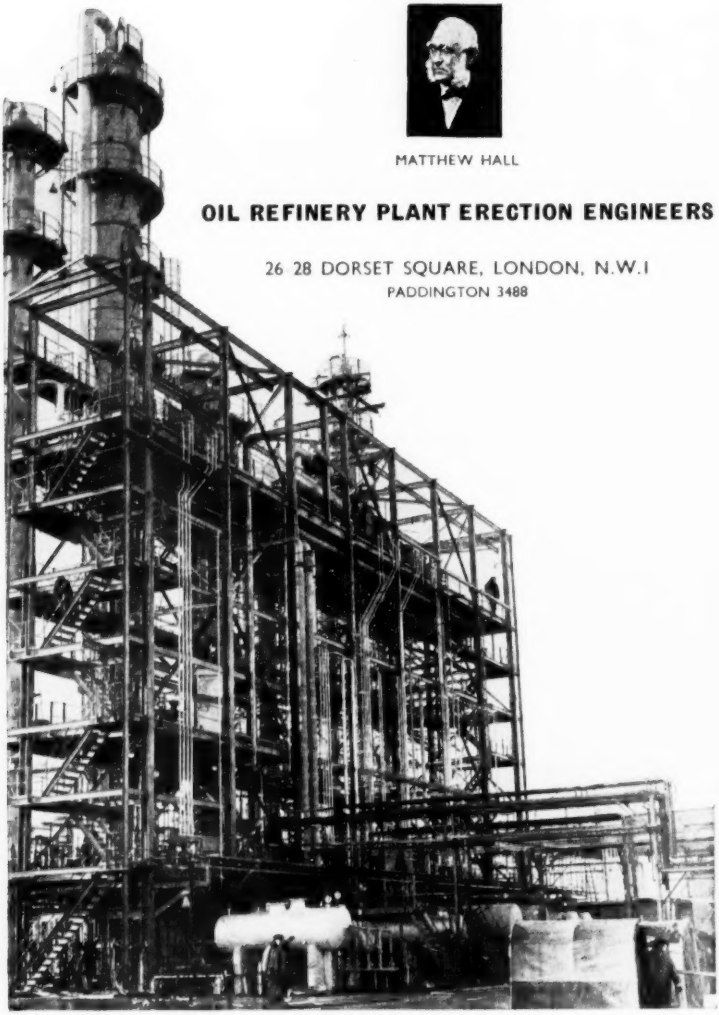

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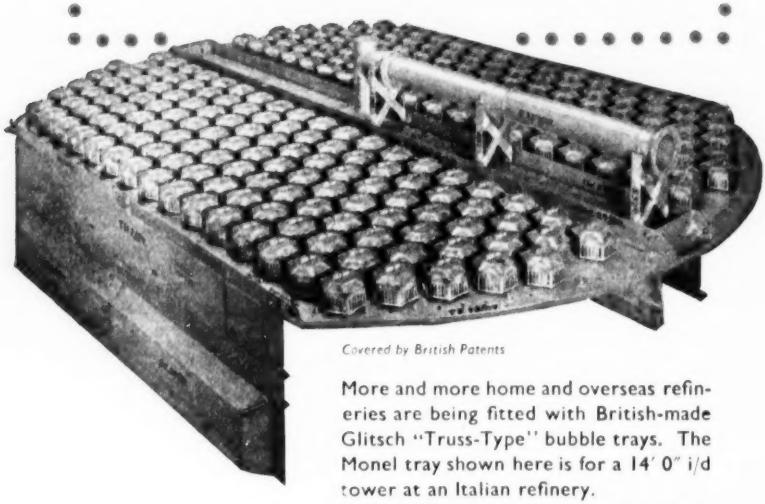

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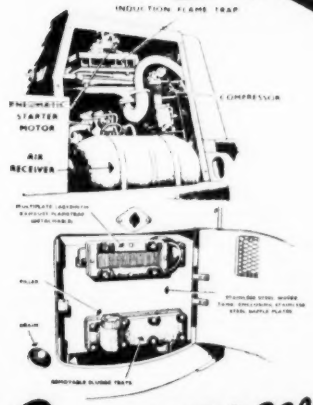

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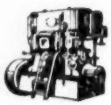

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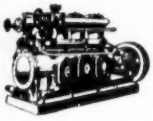

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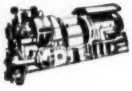

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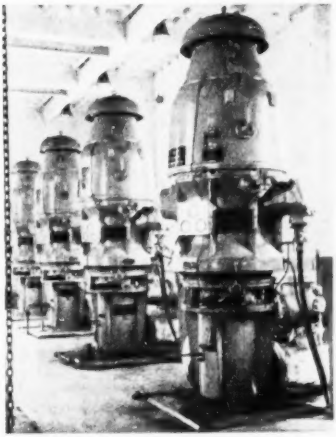

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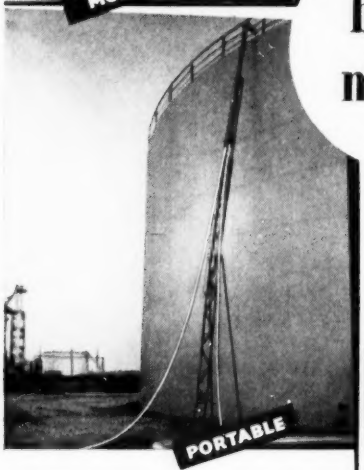

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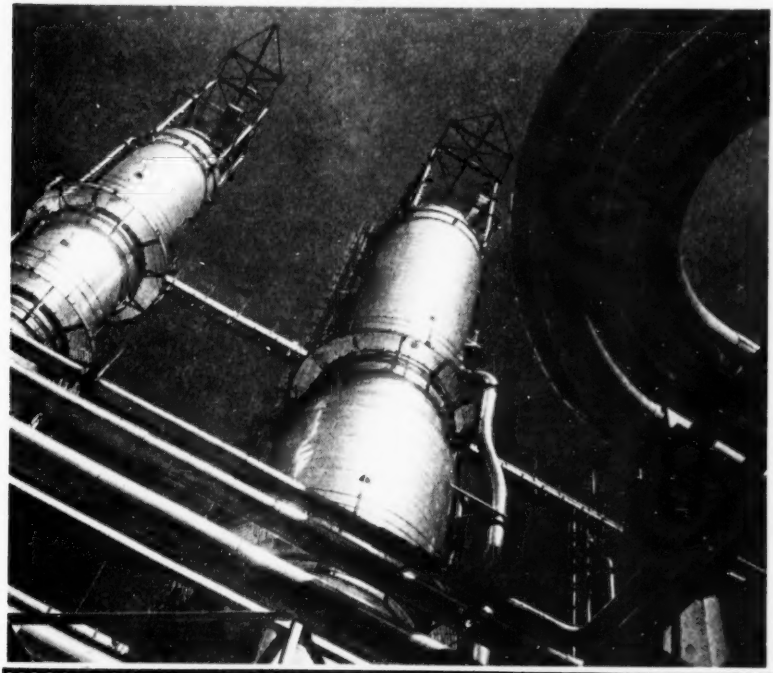

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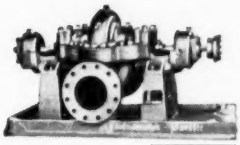

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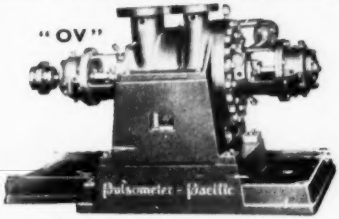

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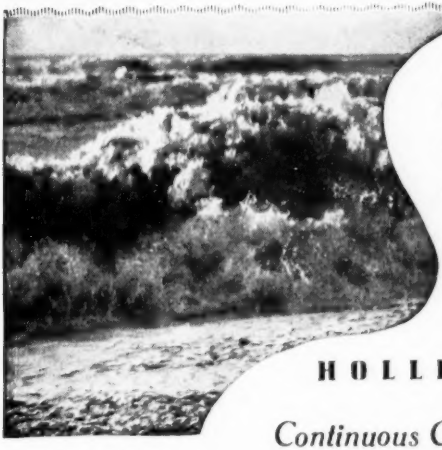

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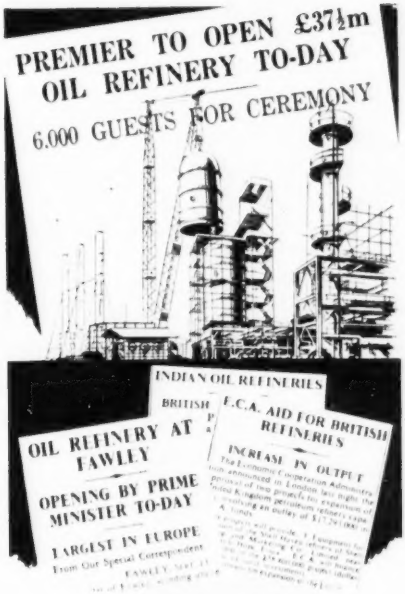

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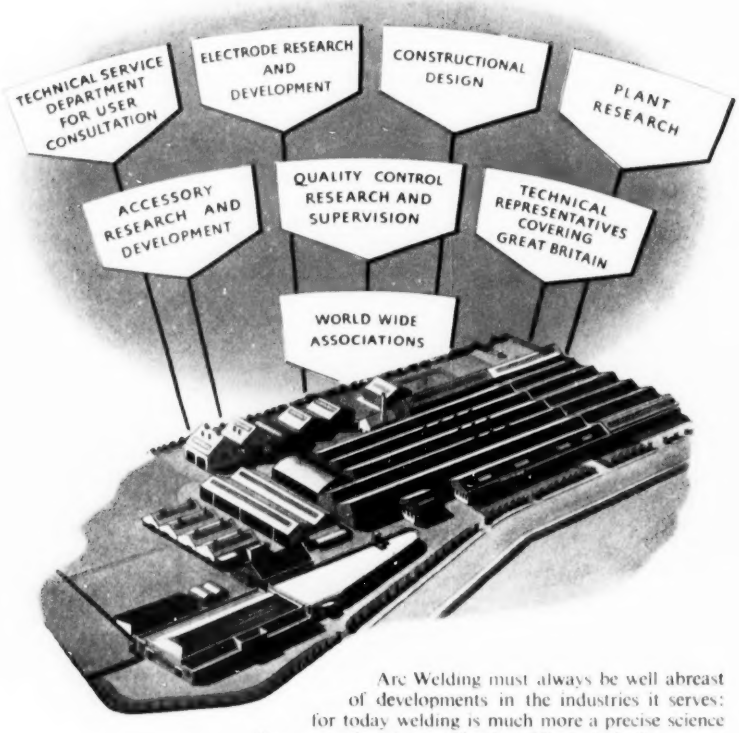

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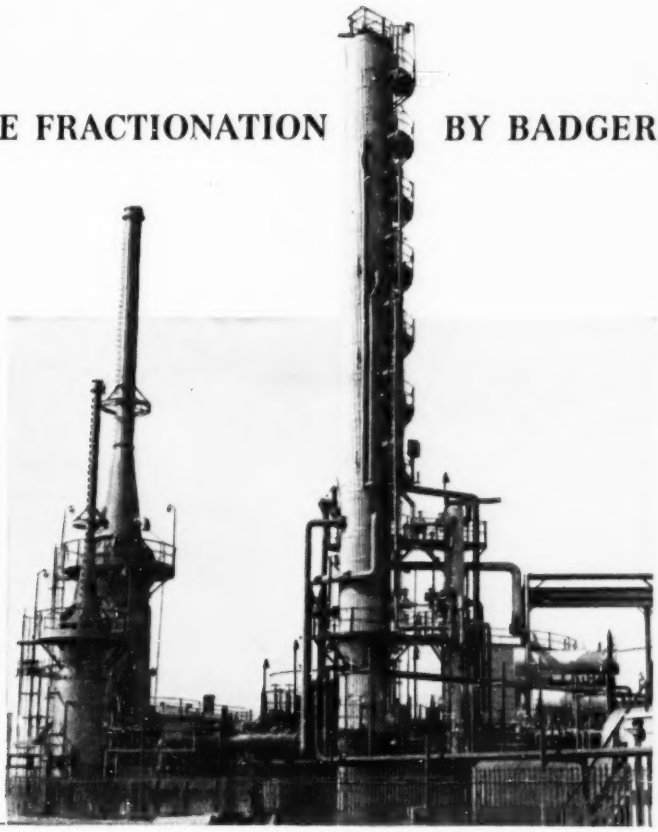

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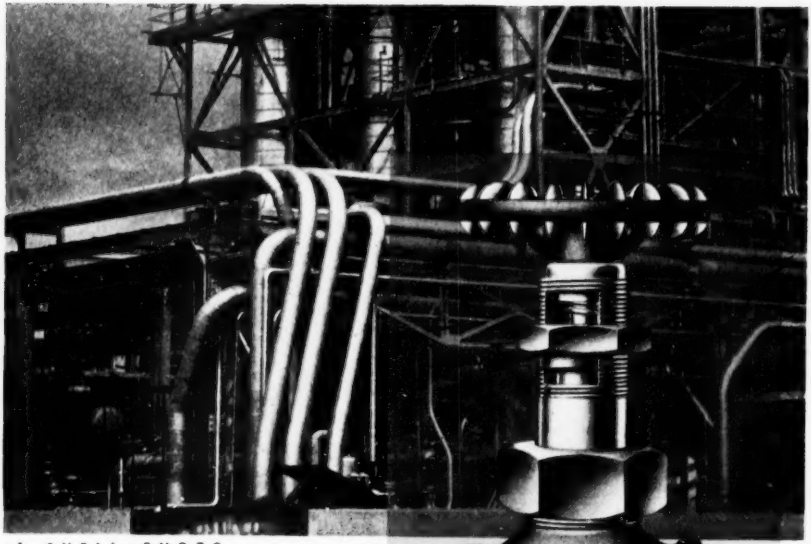

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